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Evaluating hybrid layers under organic production conditions - experimental design and test results

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Meinen Eltern

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GENERAL INTRODUCTION

German laying hen farmers are confronted with a slow structural change of housing systems. A public rejection of cage housing and an increasing demand for eggs from alternative and organic housing lead to a change of requirements for the hens used for egg production. During previous decades laying hen breeding focused on adaptability for cage housing. As a consequence, the alternative systems such as floor, aviary, free range and especially organic housing seem to generate problems concerning laying performance, behavior and mortality of hybrids. A decreased rate of lay and behavioral specifics such as feather pecking and cannibalism are reported. A special genetic component is to be recognized; performance is affected mainly by hen line. Nevertheless housing systems and especially the interaction between hen line and housing system play an important role as effects on performance and behavior.

As there is no independent test system for laying hens in Germany, a new test system may give hints on suitability of hen lines for special housing conditions. Because of the existence of genotype-environment-interactions results from station tests do not necessarily reflect hens' performance under on-farm conditions. Therefore a test of hens on practical farms can give information on effectively obtainable performance.

This study was initialized to design and optimize experimental plans, statistical analysis and conduction of an on-farm test of laying hens under organic housing conditions. It gives hints on approaches for future tests. Results from a test run with the four brown hybrids ISA Warren, Lohmann Brown, Lohmann Tradition and Tetra Brown on 16 farms and two stations show differences between hen lines and between farms and stations and effects of group size and season for laying performance, mortality and plumage condition.

Chapter One gives a general review on laying hen testing in Germany and shows how genotype-environment-interactions were analyzed in former studies. Special effects of genotype-environment-interactions under organic housing conditions are characterized.

In Chapter Two emphasis was put on experimental design. Several designs were analyzed concerning their power of test. The differences between power of tests in field and station and their combinations are shown.

Chapter Three shows results of laying performance, mortality, egg quality, feed conversion and plumage condition of the four hybrids under station conditions. Effects such as hen line, station and group size were specially focused on.

Chapter Four deals with the complete results from the farm and station test. It shows effects of hen line, farm type (station or farm) and season on performance in egg laying, mortality and plumage condition of the four hybrids. Special characteristics of data collection and analysis from on-farm tests are discussed separately.

CHAPTER ONE

Herkunftsvergleiche von Legehennen in Station und Feld unter besonderer Berücksichtigung ökologischer Haltungsverfahren

Laying hen performance tests in station and under field conditions

in organic production systems

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Dedicated to the 65th anniversary of Prof. Dr. Seeland

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EINLEITUNG

Leistungsprüfungen zum Vergleich verschiedener Herkünfte können auf Stationen oder im Feld durchgeführt werden. In Stationsprüfungen werden für zufällig ausgewählte Stichproben (random sample) der einzelnen Herkünfte die Haltungsbedingungen standardisiert (DICKERSON, 1965; FOX, 1975; ZEELEN, 1995), um die Störung der Messwerte durch Umwelteinflüsse gegenüber Praxisbedingungen zu verringern. Zudem sind Untersuchungen mit mehreren Faktoren möglich, z.B. die gleichzeitige Erfassung von Auswirkungen verschiedener Fütterungs- und Haltungssysteme. Nachteilig für die Beurteilung der Ergebnisse können sich Genotyp-Umwelt-Wechselwirkungen auswirken (LORENZ, 1963, HARTMANN und HEIL, 1980), die im Extremfall dazu führen, dass die Reihenfolge der Herkünfte in der Leistung unter Stationsbedingungen eine andere ist als unter Produktionsbedingungen.

Die Zucht und Vermehrung von Legehennen liegt weltweit in der Hand einiger weniger Unternehmen. Die jeweils eigenen Zuchtprodukte eines jeden Unternehmens werden zu Zwecken des Zuchtprogramms in internen Prüfstationen und in Vertragsbetrieben unter Praxisbedingungen getestet. Unabhängige Herkunftsprüfungen finden derzeit nicht statt.

Legeleistungsprüfungen sollen vergleichbare Leistungsunterlagen über die auf dem Markt angebotenen Zuchtprodukte liefern, die den Legehennenhaltern als Entscheidungshilfe beim Ankauf von Tiermaterial dienen können (LAUPRECHT, 1973). Der Legehennenhalter als Käufer von Junghennen soll somit einen objektiven Vergleich über die Eigenschaften der geprüften Herkünfte in allen für die Rentabilität, Produktvermarktung und Tiergesundheit bedeutsamen Leistungsaspekten erhalten. Diese beziehen sich bei Hühnern im Wesentlichen auf die Legeleistung, den Futterverbrauch, die Verluste und das Verhalten.

Die Zuchtunternehmen können aus den Ergebnissen einer unabhängigen Leistungsprüfung verschiedener Herkünfte ersehen, wie ihre Herkunft im Vergleich zu denen der Konkurrenz steht.

Dieser Bericht gibt zunächst einen Überblick über die bisherigen Arbeiten zu Interaktionen zwischen Herkunft und Haltungssystem bei Legehennen. Die rechtlichen und produktionstechnischen Besonderheiten der ökologischen Eierproduktion werden gesondert dargestellt, um auf die Kennzeichen einer Prüfung ökologisch gehaltener Legehennen hinzuweisen.

Im Weiteren wird der Frage nachgegangen, ob möglicherweise aufgrund von Genotyp-Umwelt-Interaktionen die für die praktische ökologische Eiererzeugung besonders geeigneten Herkünfte unter Stations- und Versuchsbedingungen nicht erkannt werden. Weiterhin werden versuchsplanerische Aspekte einer Herkunftsprüfung unter praktischen Öko-Bedingungen diskutiert, die auch eine Kombination mit Stationsergebnissen einschließen.

WARENTESTS UND EXPERIMENTELLE HERKUNFTSPRÜFUNGEN

Im deutschen Legehennenprüfwesen wurde das System der Random-Sample-Tests aus den USA übernommen und weiterentwickelt. Es bezeichnet den objektiven Test von unabhängigen zufälligen Stichproben aus den zu prüfenden Herkünften unter gleichen Aufzucht- und Haltungsbedingungen, wie z.B. bei FLOCK et al. (2003), FOX (1975) und HARTMANN (1974) beschrieben. Die Leistungsprüfung auf Station ermöglicht den objektiven Test und direkten Vergleich von Herkünften (Warentest), beispielsweise auch vor dem Einsatz in der Praxis oder vor Feldtests.

Neben Warentests werden experimentelle Untersuchungen zu Auswirkungen von Futter, Haltungssystem und Management auf die Leistung, Gesundheit und Mortalität (HAVERMANN, 1954) durchgeführt. In den letzten Jahren wurde auch hier verstärkt auf das Verhalten der Tiere eingegangen, da Probleme mit Federpicken und Kannibalismus bei der Umstellung von der Käfig- auf die Boden- und Freilandhaltung häufig auftreten.

Mit der Einrichtung von Prüfstationen für Legehennen wurde 1963 begonnen. Bis 1973 wurde sowohl in Käfighaltung als auch in Bodenhaltung getestet. Ab 1974 fand die Prüfung ausschließlich in Käfigen statt, die damals die gängigen Umweltbedingungen in der Praxis widerspiegelten. Von 2000 bis 2004 wurden die Legeleistungsprüfungen teilweise wieder in Bodenhaltung oder anderen praxisorientierten Haltungssystemen durchgeführt.

Das Merkmalsspektrum umfasste Legeleistung, Eiqualität, Mortalität und Futterverbrauch. Die Tiere entstammten einer zufällig ausgewählten Stichprobe von Bruteiern. Die Prüfungsergebnisse wurden in jährlichen Berichten veröffentlicht und auch über mehrere Jahre ausgewertet (FLOCK und KÜHNE, 1984, FLOCK und HEIL, 2001, HEIL, 1983, HEIL, 1985).

Ein Vorteil der Stationsprüfung zu Erhebungen im Feld liegt hier darin, dass auch Merkmale getestet werden können, die einen höheren Erfassungsaufwand benötigen, zum Beispiel Eiqualitätsdaten, Futterverbrauch und Verhaltensmerkmale (HEIL, 1991). Die neueren Legeleistungsprüfungen griffen seit 2000 teilweise auf eine Gefiederbonitur als Hilfsmerkmal zur Messung der Federpickaktivität zurück (ANON., 2003).

In Deutschland finden heute keine unabhängigen Herkunftsprüfungen auf Station mehr statt. Bis vor einigen Jahren testeten Prüfstationen in Neu-Ulrichstein (2002), Kitzingen und Haus Düsse (2004) in Käfig-, Boden- bzw. Volierenhaltung. Letztere stehen derzeit als Versuchsstationen für Futtermittel oder Haltungselemente zur Verfügung.

Genotyp-Umwelt-Interaktionen

Unterschiedlich gerichtete Leistungsdifferenzen zwischen Herkünften in verschiedenen Haltungssysteme lassen darauf schließen, dass einzelne Herkünfte mit bestimmten Haltungssystemen in einigen Merkmalen besser zurecht kommen. Es treten also zwischen den Herkünften und den verschiedenen Haltungssystemen Wechselwirkungen, sogenannte Genotyp-Umwelt-Interaktionen, auf.

Gleichartige Reaktionen verschiedener Herkünfte auf Änderungen im Haltungssystem ohne Interaktion werden als additiv bezeichnet. Treten Interaktionen auf, so können diese ohne oder mit Verschiebungen der Rangfolge der einzelnen Herkünfte beobachtet werden. Eine Verschiebung der Rangeinstufung muss für jede Herkunft, jedes Haltungssystem und in jedem Merkmal neu geschätzt werden (Heil, 1983). Wechselwirkungen können durch Mikroeffekte, z.B. die Position der Tiere im Stall oder schleichende Infektionen, oder durch Makroeffekte, wie lenkbare Umweltbedingungen und Marktorientierung, ausgelöst werden (Petersen, 1986).

Die daraus folgenden Interaktionen sind im Falle der Mikroeffekte sporadisch und nicht vorhersehbar. Die Makroeffekte können gerichtete, wiederholbare Interaktionen hervorrufen, die beinhalten, dass Genotypen in spezifischen Umweltverhältnissen ihre optimale Leistung bringen.

Für die Legehennenhaltung bedeutet dies, dass Änderungen im Haltungssystem unterschiedliche Reaktionen zwischen den Herkünften zur Folge haben können und die Leistungen aus standardisierten Prüfungen nicht uneingeschränkt auf die Praxisumwelt übertragbar sind.

Interaktionen zwischen Herkünften und Haltungssystemen in der Eierproduktion

Solche Interaktionen für die Eierproduktion zeigten bereits frühere Untersuchungen im Zusammenhang mit der Umstellung von der Boden- auf die Käfighaltung. In Legeleistungsprüfungen von Zufallsstichproben aus kommerziellen Herkünften auf Stationen konnten Interaktionen sowohl zwischen Herkünften und Boden- bzw. Käfighaltung als auch zwischen Herkünften, Haltungssystemen und Stationen nachgewiesen werden (unterschiedliche Gestaltung der Haltungssysteme). Tabelle 1 stellt Wechselwirkungen zwischen Herkünften und Boden- und Käfighaltung dar (Heil, 1985).

Im Käfig kamen bei diesen Untersuchungen zwischen einer und fünf Hennen je Käfig zum Test. Pro Tier standen zwischen 372 und 622 cm^2 Platz, bei Einzelhaltung 1394 cm^2 zur Ver-

Tab. 1: Durchschnittliche Leistungen in Boden- und Käfighaltung bis 1985, Differenz zur Käfighaltung und die Ergebnisse der statistischen Signifikanzprüfungen der Differenz zwischen den Haltungsformen und der Interaktionen zwischen Herkünften und Haltungsformen, nach HEIL, 1985.
Average performance in floor- and cage-housing until 1985, differences to cage-housing and the results of the statistical significance tests of the difference between housing-systems and the interactions between hybrids and housing-systems.
- = n.s.: $p > 0{,}05$; *: $p \leq 0{,}05$; ** : $p \leq 0{,}01$; ***: $p \leq 0{,}001$

Quelle	Legeleistung pro Ø-Henne (%)			Eigewicht (g)			Futterverwertung Kg Futter/kg Eimasse			Verluste (%)		
	Bo	Diff. Bo-Kä	Inter-aktion	Bo	Diff. Bo-Kä	Inter-aktion	Bo	Diff. Bo-Kä	Inter-aktion	Bo	Diff. Bo-Kä	Inter-aktion
GOWE (1956)	61	9**	-	58	0 –	**	3,35			24	5 *	-
NORDSKOG und KEMPTHORNE (1960)			**			-						-
LÜKE et al. (1973)	63	-10**	**	60	-1**	**	3,35	0,63**	**	13	0 –	-
CHRISTMAS et.al. (1974)	69	1**	-	59	-1 –	-	2,58	0,07 –	-	27	-3 –	-
	69	2**	-	58	-1 –	-	2,70	0,01 –	*	11	-5 –	-
	67	1 –	**	60	-1 –	-	2,74	0,16 –	*	9	-5 –	-
HAGGER et.al. (1974)	70	-2**	*	59	-1 **	-	2,90	0,21**		10	1 –	*
LÜKE et.al. (1975)	65	-7**	-	61	0 -	-	3,22	0,32**	*	8	0 –	**
DICKERSON et.al. (1976)	72	3**	-	59	-1 –	-	2,76	0,21**	-	11	-1 –	*
HEIL (1985)	65	-18	***	62,6	-0,2	-	2,88	0,47	***	8	1,8	-
	73	-2	***	60,9	-0,2	-	2,75	0,12	***	7,5	-0,8	-

fügung. Die Gruppengröße in der Bodenhaltung lag zwischen 21 und 70 Tieren je Abteil; jedes Tier hatte hier zwischen 1914 und 3720 cm^2 Platz. Auffallend sind die geringeren Besatzdichten in den fünfziger Jahren mit 2,7 Tieren je m^2 bei GOWE (1956), die 1973 bei LÜKE et.al. bereits erhöht waren (4,5 Tiere/m^2). Heute werden je m^2 bis zu neun Tiere gehalten, in der ökologischen Haltung bis zu sechs Tiere.

HEIL fand 1985 in den verschiedenen Arbeiten zur Umstellung von der Boden- auf die Käfighaltung Wechselwirkungen zwischen Herkünften und Boden- und Käfighaltung in den Merkmalen Legeleistung, Eigewicht, Futterverwertung und Verluste. Bei eigenen Zusammenfassungen der Legeleistungsprüfungen aus der Schweiz und Belgien konnte er diese bezüglich Legeleistung und Futterverwertung bestätigen. Die Unterschiede in den Leistungen zwischen Boden- und Käfighaltung sind dabei nicht richtungsgleich, d.h. es ergeben sich Rangverschiebungen.

Außerdem beschreibt HEIL 1985 schwache Signifikanzen der Interaktion bezüglich des Körpergewichts am 500. Tag in den beiden Prüfungsgruppen. In der Schweiz kam eine mittlere Signifikanz im Merkmal Alter bei 50 % Legeleistung dazu Hochsignifikante Interaktionen in den Merkmalen Eizahl und Eimasse je Anfangshenne waren zu erkennen.

In neueren Untersuchungen werden aufgrund der geänderten Voraussetzungen bezüglich der Haltungsvorschriften vor allem ausgestaltete Käfige, Volieren- und Auslaufhaltungen verglichen. Auch hier sind immer wieder Interaktionen nachgewiesen, die die Einschätzung von Leistungen verschiedener Herkünfte erschweren. Im Vergleich verschiedener Käfige ergaben sich teilweise statistisch hochsignifikante Interaktionen im Merkmal Körpergewicht (ABRAHAMSSON, 1995b).

LEYENDECKER (2003) fand bei sämtlichen Legeleistungs- und Eiqualitätsmerkmalen mittel bis hoch signifikante Interaktionen zwischen Käfig-, intensiver Auslauf- und Volierenhaltung und den Legelinien. Diese wurden bei ABRAHAMSSON (1995 a und b) und VITS et.al. (2005) nur bezüglich der Knick- und Schmutzeier gemessen. Weitere Eiqualitätsmerkmale waren bei LEYENDECKER nicht signifikant interaktiv, VITS et.al. (2005) konnten jedoch für die Dotterfarbe niedrige und für Haugh Units, Schalengewicht und Schalendichte hohe Signifikanzen der Interaktion zwischen den Herkünften und verschiedenen ausgestalteten Käfigen nachweisen. Die Unterschiede zwischen den Haltungssystemen lassen vermuten, dass manche Linien in Boden- oder Volierenhaltung mehr Eier verlegen, d.h. die Nestgängigkeit nicht stark genug ausgeprägt ist. Dies führt zu einem erhöhten Anteil an Knick-, Schmutz- und Brucheiern. Bei VON KLEIST (1985) waren keine Unterschiede in der Dotterfarbe zwischen verschiedenen Käfigtypen zu finden.

Für die Futterverwertung ergaben sich sowohl zwischen Herkünften und Käfigen und Volieren (ABRAHAMSSON, 1995a) als auch zwischen Herkünften und Käfigen, Volieren und Auslaufhaltungen signifikante Interaktionen (ABRAHAMSSON, 1995a und LEYENDECKER, 2003). Es ist anzunehmen, dass dies vor allem an der Futterverschwendung in Volieren- und Bodenhaltungen liegt, die gegenüber Käfighaltung stark erhöht ist.
In einer zweiten Untersuchung konnte LEYENDECKER signifikante Interaktionen zwischen Legelinie und Haltung bezüglich der Knochenfestigkeit der Tibia nachweisen. ABRAHAMSSON et.al. (1996) erhielten außerdem hochsignifikante Herkunft-Umwelt-Interaktionen in den Merkmalen Gefiedersauberkeit, Fußballenabszesse, Fußballengeschwüre und Krallenzustand.
Die Reaktionen von Herkünften auf andere Haltungssysteme sind auch geprägt von Unterschieden zwischen verschiedenen Stationen/Betrieben (HEIL, 1985). Das bedeutet, dass der Effekt des Haltungssystems zusätzlich durch unterschiedliche Betriebsvoraussetzungen wie Fütterung, Management, Stallausgestaltung etc. beeinflusst werden kann. Somit muss auch zwischen Feld- und Stationsergebnissen bei gleichem Haltungssystem mit Interaktionen gerechnet werden.
Genotyp-Umwelt-Interaktionen wurden bisher für Leistungsmerkmale von Legehennen beschrieben. Für Verhaltensmerkmale wie Federpicken und Kannibalismus sind der Literatur keine Untersuchungen zu Wechselwirkungen dieser Art zu entnehmen, obwohl eine deutliche Mehrbelastung der Tiere durch die genannten Verhaltensweisen z.B. durch eine Erhöhung der Tierdichte (NICOL et.al., 1999), in alternativen Haltungssystemen ohne Auslauf (MAHBOUB, 2004, KREIENBROCK et.al., 2004) oder durch einstreulose Aufzucht (HUBER-EICHER und SEBÖ, 2001) zu beobachten ist und dabei Unterschiede in der Reaktion verschiedener Herkünfte auftreten.
Bei LANGE (1997) war aus den Ergebnissen der Legeleistungsprüfungen auf Station - trotz Leistungsdifferenzen, die zu Rangverschiebungen zwischen den Herkünften in den Haltungssystemen führten - keine statistische Signifikanz der Interaktion nachzuweisen.

MISCHHALTUNGEN VON HERKÜNFTEN

Versuche zum Herkunftsvergleich werden meist mit getrennt gehaltenen Herkünften geplant (eine Herkunft je Gruppe). Sowohl praktische Legehennenhalter als auch einige wissenschaftliche Versuchsansteller halten aber auch verschiedener Rassen oder Hybriden in gemischten Gruppen in Verhältnissen zwischen 1:1 und 1: 10.
JAAP (1954) erhielt in einem Test von gemeinsam aufgezogenen Hybriden keine Unterschiede zwischen Mischhaltungen und getrennt gehaltenen Hennen in der Legeleistung und im Kör-

pergewicht. Möglicherweise sind Leistungsunterschiede in der Mischhaltung durch positiv wirkendes Konkurrenz- und Nachahmungsverhalten (z.B. für Nestgängigkeit) zu erklären.
Allerdings besteht bei einer Neumischung von Gruppen älterer, einander unbekannter Tiere ein erhöhtes Risiko von aggressivem Bepicken, Federpicken und Kannibalismus (CLOUTIER und NEWBERRY, 2002a, HAUSER und HUBER-EICHER, 2004). Für kleinere Hennen und solche mit größeren Kämmen wurden ebenfalls größere Risiken für kannibalistische Angriffe gefunden (CLOUTIER und NEWBERRY, 2002b).
Bei LOWE (1976) gab es in der Mischhaltung höhere Verluste bei den leichteren Leghorn-Tieren; diese waren in der Rangfolge offensichtlich den Vergleichstieren Rhode Island Red unterlegen.
Die Mischung von Herkünften kann also die Leistung verändern, diese ist deshalb nicht vergleichbar mit Untersuchungen der Leistung getrennt gehaltener Herkünfte. Darum müssen Ergebnisse aus gemischter Haltung prinzipiell als neue Herkünfte bewertet werden. Für einen Feldtest von Hybriden gleicher Eifarbe eignet sich die Mischhaltung selbstverständlich auch deshalb nur bedingt, weil eine getrennte Erfassung der Leistungen der einzelnen Herkünfte kaum möglich ist. Praktiker sehen aber in der Mischhaltung z.B. von Weißlegern und Braunlegern im Verhältnis 1:4 jedoch eine Chance, die Nestgängigkeit der Braunleger zu verbessern. Die Leistungsprüfung von Herkunftsmischungen - z.B. von Weiß- und Braunlegern - könnte also durchaus eine mögliche Fragestellung einer Herkunftsprüfung sein.

INTERAKTIONEN ZWISCHEN HERKUNFT UND ÖKOLOGISCHER BZW. KONVENTIONELLER HALTUNG

Die Rahmenbedingungen der ökologischen Haltung beinhalten engere Restriktionen als die für konventionelle Haltungssysteme. Die Vorschriften resultieren aus der EU-Gesetzgebung (CONSLEG: 1991R2092 - 01/05/2004, 2004) und den Richtlinien der Ökoverbände.
Laut EU-Richtlinie dürfen nicht mehr als 3.000 Tiere in einer Gruppe gehalten werden. Die Tiere müssen mindestens für ein Drittel ihres Lebens ständigen Zugang zu Auslauf haben, und es dürfen pro Tier nicht weniger als 4 m^2 Außenfläche zur Verfügung stehen. Der Stall muss eine ausreichend große Kotgrube, Sitzstangen und mindestens ein Drittel der Gesamtfläche eingestreut mit Stroh, Holzspänen, Sand oder Torf aufweisen.
Lichtprogramme dürfen nur bis maximal 16 h am Tag durchgängig Kunstlicht geben, eine achtstündige durchgehende Ruhephase ohne Kunstlicht ist notwendig. Die Jungtiere dürfen nur in Ausnahmefällen aus nicht-ökologischer Aufzucht stammen. Es müssen ökologisch erzeugte Futtermittel verwendet werden. Extraktionsschrote, Tierkörpermehle, Wachstumsför-

derer und Kokzidiostatika sind verboten. Ein Einsatz von künstlich zugesetzten Aminosäuren im Futter ist nicht erlaubt.
Die vorbeugende Maßnahme des Schnabelkupierens ist (im Gegensatz zur konventionellen Haltung, wo auf Antrag kupiert werden darf) grundsätzlich verboten. Der vorbeugende Einsatz von allopathischen Arzneimitteln und Antibiotika ist untersagt.
Die Unterschiede zur konventionellen Geflügelhaltung sind also so umfangreich, dass die Ökohaltung als eigenes Haltungssystem betrachtet werden sollte. Die Gefahr von Kannibalismus wird von APPLEBY und HUGHES 1991 in alternativen Systemen höher eingeschätzt als in der Käfighaltung. Die Autoren bewerten die Gefahr für Federpicken in der Käfighaltung als höher. In aktuellen Erhebungen auf Praxisbetrieben tritt jedoch auch in Boden- und Volierenhaltungen in erhöhtem Maße Federpicken auf. Sowohl die LAYWEL- (2006) als auch die Epileg-Studie (KREIENBROCK et al., 2004) dokumentieren in Käfighaltung höhere Produktivitätsdaten und niedrigere Werte für Feder- und Zehenpicken sowie Kannibalismus im Vergleich zu Boden-, Volieren- und Auslaufhaltung. In der Ökohaltung können vor allem das Verbot des Schnabelstutzens und der Verfütterung von synthetischen Aminosäuren (JEROCH et al., 2002) diese Probleme noch verstärken. Eine ausreichende Versorgung der Legehennen mit Aminosäuren allein aus den natürlichen Futterkomponenten der ökologischen Futterversorgung bereitet große Schwierigkeiten.
Der Infektionsdruck bei Hennen in Boden- und Auslaufhaltung ist höher als in Käfig- und Kleingruppenhaltung (MORGENSTERN und LOBSIGER, 1994, BRADE, 2000), da die Tiere direkt mit Kot, Parasiten und Infektionserregern z.B. aus der Einstreu und durch Wildvögel oder Ratten in Kontakt kommen.
Vor dem Hintergrund der nachgewiesenen Interaktionen von Herkünften mit verschiedenen Käfigsystemen (ABRAHAMSSON, 1995b; VITS et al., 2005), verschiedenen Volierensystemen (ABRAHAMSSON, 1995a) sowie Käfig-, Volieren- und intensiver Auslaufhaltung (LEYENDECKER, 2003) sind Interaktionen von Herkünften mit konventioneller und ökologischer Haltung zu erwarten. Diese können sowohl Legeleistung und Knochenfestigkeit (LEYENDECKER, 2003) als auch Eiqualität (VITS et al., 2005) und Krallenzustand (ABRAHAMSSON, 1995a, ABRAHAMSSON, 1995b) betreffen. PREISINGER et al. (1999) vermuten Wechselwirkungen vor allem für die Verhaltensmerkmale Neigung zu Kannibalismus, Nestgängigkeit, Auslaufnutzung und für den Befiederungszustand.
Ein Feldtest auf ökologischen Praxisbetrieben erscheint deshalb als passendes Mittel, um die Eignung verschiedener Herkünfte speziell für die Bedingungen der Ökohaltung zu prüfen. Eine Stationsprüfung kann vor allem für solche Merkmale, die unter Praxisbedingungen

schwer zu erfassen sind (z.B. Futterverbrauch, Eiqualität, detaillierte Gefiederbonitur) eine wertvolle Ergänzung bieten.

SCHLUSSFOLGERUNGEN FÜR EINEN FELDTEST IN ÖKOLOGISCHEN LEGEHENNENHALTUNGSBETRIEBEN

Für den Hennenhalter im Ökolandbau ist es relativ schwierig, unabhängige und vergleichbare Prüfdaten über verschiedene Zuchtprodukte zu erhalten. Verfügbare Angaben über verschiedene Herkünfte sind aufgrund von Genotyp-Umwelt-Interaktionen nur eingeschränkt von einer Haltungsform auf eine andere und von Stationsbedingungen auf Praxisbedingungen übertragbar. Vor allem unter ökologischen Bedingungen sind die Reaktionen der in konventioneller Haltung geprüften Tiere schwer vorhersehbar. Eine unabhängige Leistungsprüfung für Legehennen unter ökologischen Bedingungen gibt es derzeit nicht. Allein die Herkunftsvergleiche der Prüfstation Kitzingen bei konventioneller und ökologischer Fütterung geben Hinweise auf Leistungsunterschiede einzelner Herkünfte (LFL BAYERN, 2006).

Jedoch besteht für die Öko-Ei-Produktion spezieller Bedarf nach unabhängigen Informationen über das Produktionsverhalten verschiedener Herkünfte bei ökologischer Haltung. Die Entwicklung eines unabhängigen Feldtests für ökologisch gehaltene Legehennenhybriden kann die oben genannte Anforderung an Legeleistungsprüfungen erfüllen.

Eine Mischhaltung von Hybriden sollte als eine eigene Herkunft behandelt werden, da die Mischhaltung eine Möglichkeit darstellt, die Nestgängigkeit von Braunlegern zu verbessern.

Die zu erfassenden Daten sollen eine umfassende Leistungs- und Verhaltensinformation über die getesteten Herkünfte geben, neben der Legeleistung sind Daten über Abgänge zu erheben sowie solche Merkmale, die Rückschlüsse auf das Verhalten erlauben. Die Datenerfassung muss praktikabel und bezahlbar bleiben.

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ZUSAMMENFASSUNG

Der Beitrag beschreibt die Bedingungen von Legeleistungsprüfungen in Deutschland mit Bezug auf Genotyp-Umwelt-Interaktionen. Außerdem werden die Besonderheiten der Eierpro duktion auf ökologischer Basis herausgestellt. Daraus werden Anregungen für ein Konzept einer zukünftigen Feldprüfung von Legehennen erarbeitet.

In Deutschland werden keine offiziellen Legeleistungsprüfungen der Länder mehr durchgeführt. Unabhängige Leistungsinformationen aus Herkunftsvergleichen stehen daher nur aus einzelnen Prüfungen (LFL BAYERN, 2006) zur Verfügung. Interaktionen zwischen Legehennenherkünften und unterschiedlichen Haltungssystemen sind nach Literaturangaben gut belegt. Für die Ökoproduktion von Eiern ist aufgrund der produktionstechnischen Unterschiede zur konventionellen Produktion ebenfalls mit solchen Wechselwirkungen zu rechnen. Deshalb

braucht die ökologische Eierproduktion eine Leistungsprüfung, die auf die speziellen Produktionsbedingungen abgestimmt ist. Die Entwicklung eines Feldtests für Legehennen in ökologischer Haltung kann daher ein Weg sein, das gegenwärtige Informationsdefizit der Landwirte über die Leistung und das Verhalten erhältlicher Zuchtprodukte unter Öko-Bedingungen zu verringern. Das Konzept muss eine praktikable Datenerfassung gewährleisten. Ein geeignetes und kostengünstig durchführbares Versuchsdesign zur Ermittlung der durchschnittlichen Eignung von Legehennenherkünften für die ökologische Haltung muss dazu entwickelt werden.
<u>Stichworte</u>: Legehenne, Ökologische Landwirtschaft, Legeleistungsprüfung, Genotyp-Umwelt-Interaktion

SUMMARY:

Laying hen performance tests in station and under field conditions in organic production systems

This paper describes the current methods used for laying hen performance tests in Germany. Specific emphasis is placed on illustrating the characteristics of ecological egg production. The concept of a future coordinated field test for ecological egg production is set forth.
Official laying hen performance tests are no longer implemented by the lands in Germany; independent performance information on breed comparisons is therefore unattainable. Information on hybrid breed performance for layers under ecological production conditions is even more difficult for producers to obtain. The interactions between various laying hen hybrids and different housing systems are well documented, and almost always result in changes in group ranking.
The reciprocal effects between breeds and housing systems play an important role in ecological egg production, as these interactions are more pronounced than those observed in conventional production systems.
The development of a field test for laying hens in ecological systems can be a way to reduce the information deficit of farmers regarding performance and behaviour of hybrid hens under ecological conditions. The concept must ensure practicable and economical data acquisition. A suitable and economical test design for an evaluation of the average suitability of laying hen hybrids for organic farming has to be developed.
<u>Keywords:</u> laying hen, ecological farming, laying performance test, genotype-environment-interaction

CHAPTER TWO

Considerations on Experimental Design and Power of a Combined Field and Station Test of Layer Hybrids

Aspekte der Versuchsplanung und Güte einer kombinierten Feld- und Stationsprüfung von Legehennenhybriden

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INTRODUCTION

Experimental capacities for random-sample evaluations of layer hybrids (DICKERSON, 1962) have been considerably downsized in Germany as well as in other countries. However there is still a significant demand for the results of such evaluations, especially from tests in environments reflecting practical conditions (FLOCK, 1970, FLOCK and HEIL, 2002). Data on performance and suitability of modern layer hybrids, especially under practical organic conditions and non-cage housing systems, is required. This is amplified by the fact that for many years almost all breeding work has been done in a cage environment, which could be a reason for undesirable genotype-environment interactions.

On-farm comparisons of genotypes might be a source of information matching the requirement for a test environment as close to practical production circumstances as possible. In addition, it may help to overcome the current shortening of station test capacity. The latter only applies to traits which can easily be recorded on farms, such as egg number or mortality rates. Data on other traits such as feed conversion or detailed measurements of animal behavior still need to be collected under station conditions. Combined on-farm and station schemes for comparing layer hybrids may therefore have potential to provide more information than testing genotypes in a single environment.

In this article we investigate some important aspects of the experimental design of such evaluation trials. The effects of the number of different genotypes, total experimental size, number of hen groups per farm and number of genotypes per farm on power of test have been evaluated. A combination of on-farm and station tests was investigated as well. Choice of designs and discussion of results were done with special emphasis on organic egg production.

CHOICE OF EXPERIMENTAL DESIGNS AND STATISTICAL METHODS

A common feature of all experimental designs we considered is that observations correspond to groups of hens. From the experiences of a practical test-run of a combined on-farm and on-station evaluation of different layer hybrids (GLAWATZ et al., 2009, in preparation), it was deduced that farms with two or, in fewer cases, four contemporary groups can be recruited for participation. Although organic egg farms with more groups exist, their participation was hampered by technical reasons, e.g. automatic egg collection devices do not allow to record egg numbers separately for each group without considerable extra effort. Therefore we mainly focused on experimental designs with two groups per farm and considered only few layouts in which some of the farms keep four or six groups.

The number of lines per farm was restricted to two in all scenarios (with a single exception), even though a certain fraction of the farms was assumed to keep more than two groups. The reason is organisational, because organic egg farms usually cooperate with specialised rearing farms and these refuse to allocate young hens from too many different lines, especially for small organic farms. This approach was also approved by NORDSKOG and KEMPTHORNE (1960), who quoted that the statistically most efficient comparison is the test of 2 lines on 1 farm.

The number of different lines included in the comparison was set to a maximum of four in order to assure sufficient power. Total experimental size in terms of number of groups was derived by a number of up to 33 participating farms (more farms were considered to be difficult to recruit and to minister), leading to a maximum of 66 groups on farm, when two groups per farm were assumed. The maximum number of groups in a single run was set to 45 on station, corresponding to the capacity of the test station in Kitzingen.

Table 1: Different experimental designs analyzed with respect to their power to detect differences between lines. The effective number of groups per line n_e was rounded to the next half integer value.

Design	Hen lines	Farms	Groups on station	Repetitions	Groups in total	Farms with 2 groups	Farms with 4 groups	Thereof farms with 3 lines	n_e
D1	2	33	-	-	66	33	-	-	33.0
D2	3	33	-	-	66	33	-	-	16.5
D3	4	33	-	-	66	33	-	-	11.0
D4	3	-	15	-	15	-	-	-	5.0
D5	3	-	33	-	33	-	-	-	11.0
D6	3	-	45	-	45	-	-	-	15.0
D7	3	-	66	-	66	-	-	-	22.0
D8	3	-	33	2	66	-	-	-	22.0
D9	3	-	33	3	99	-	-	-	33.0
D10	3	33	33	-	99	33	-	-	27.5
D11	3	24	-	-	66	15	9	-	16.5
D12	3	24	-	-	66	15	9	6	18.0

In total twelve different experimental designs were analysed with respect to their power (Table 1). The first three designs consider on-farm testing only. On 33 farms a total of 66 groups were assumed in all cases, and the number of different genotypes was varied from 2 to 4. Designs in which part of the farms keep four hen groups were also considered (Table 1, designs D11 and D12), in order to investigate the effect of distributing groups on a variable number of farms. Six designs (D4 to D9) considered station testing only, differing in the number of groups per line (from 5 to 33), either in a single or in two or three repeated runs. The numbers of groups per hen line were chosen according to LAUPRECHT et al. (1973), who recommended a minimum of 5 and a maximum of 15 groups per line. Pure station-testing is particularly of interest for traits like egg quality or feed conversion, which can only be measured under test station conditions. The number of 45 groups in total corresponds to the test capacity in Kitzingen, a higher group number hence requires repetition or the participation of a second test station. Finally a design (D10) including three genotypes both on farm and on station with a total group number of 99 was evaluated.

For all different designs the effects of station (or station by repetition) and farms were treated as fixed block effect, where the block size could vary between blocks, e. g. between station and farms. In all scenarios but one the number of groups per line was equal for all genotypes, resulting in experiments which were balanced with regard to genotype but not with respect to blocks. Design D3 achieved this approximately with either 16 or 17 groups per line.

As underlying model we used

$$y_{ijk} = \mu + b_i + h_j + e_{ijk} \tag{1}$$

where b_i is the fixed effect of block number i (either station or one of the farms) with $i = 1,\cdots,n$, h_j is the fixed effect of hen line j ($j = 1,\cdots,v$), $k = 1,\cdots,N$ is the index of group number k with hens of line j and on block number i. Interactions between genotype and environment (field/station) were assumed to be absent.

Experimental power was calculated for a global F-Test, where the null hypothesis $H_0 : h_1 = h_2 = \cdots h_v = 0$ corresponds to a situation in which no differences between genotypes exist at all and under the alternative hypothesis H_A that at least a single hen line differs from the others. It was assumed that all hen lines are equal except for one, for which a difference of d standard deviations to all other lines was inserted. Observations were assumed to be independently normally distributed with variance $\sigma_e^2 = 1$. Power curves were generated by a stepwise increase of d from 0 to 2.0, with increments of 0.1. For each particular d and each experimental design the power $1-\beta$ was calculated as $P(F > S_{0.95})$, where $S_{0.95}$ is the 95% percentile of a central F-distribution with v and o-rank(X) degrees of freedom (o is the total number of observations and X is the design matrix). $P(F > S_{0.95})$ was derived by numerical integration of the density function of a non-central F-distribution with the same degrees of freedom as before and non-centrality parameter *nc*. The latter can be expressed (SEARLE, 1971, p 190) as

$$nc = (\mathbf{K}'\mathbf{b})'(\mathbf{K}'\mathbf{G}\mathbf{K})^{-1}(\mathbf{K}'\mathbf{b})/2\sigma^2 \tag{2}$$

where $H_0 : \mathbf{K'b} = 0$ denotes the linear hypothesis of no differences between lines, b is the parameter vector and G is a generalised inverse of $\mathbf{X'X}$.

The contrast-matrix **K** was constructed as in this example with n blocks on v=3 lines:

$$\mathbf{K} = \begin{bmatrix} 0 & 0 \\ 0 & 0 \\ \vdots & \vdots \\ 0 & 0 \\ \hline 1 & 1 \\ -1 & 0 \\ 0 & -1 \end{bmatrix} = \begin{bmatrix} \mathbf{0} \\ \hline \mathbf{H}_k \end{bmatrix} \text{ with the design matrix } \mathbf{X} = \begin{bmatrix} 1 & 1 & 0 & 0 & 1 & 0 & 0 \\ 1 & 1 & 0 & 0 & 0 & 1 & 0 \\ 1 & 0 & 1 & 0 & 0 & 1 & 0 \\ 1 & 0 & 1 & 0 & 0 & 0 & 1 \\ 1 & 0 & 0 & 1 & 1 & 0 & 0 \\ 1 & 0 & 0 & 1 & 0 & 0 & 1 \end{bmatrix} \tag{3}$$

and corresponding b-vector

$$\mathbf{b} = \begin{bmatrix} \mu \\ b_1 \\ \vdots \\ b_n \\ h_1 \\ \vdots \\ h_v \end{bmatrix} = \begin{bmatrix} \mu_b \\ b_b \\ h_b \end{bmatrix} \quad \text{and} \quad \mathbf{h_b} = \begin{bmatrix} 0 \\ d \\ 0 \end{bmatrix} \tag{4}$$

For the sake of power calculations only the lower part $\mathbf{h_b}$ of **b** must be specified: in all cases the effect of the second line was set equal to d and all other line effects were set equal to zero. The generalised inverse of **X'X** was chosen appropriately in such a way, that the first line-effect h_1 received a zero estimate, d is thus the difference between the first and the second line (or, when more than two lines were considered, between the second line and all other lines).

The formula (6) for the non-centrality parameter comprises the term **K'GK**, which can be interpreted as the covariance-matrix for the differences between hen-lines. In our example with three genotypes and the lower part $\mathbf{H_k}$ of the **K**-Matrix specified as in (3) **K'GK** is a 2×2 matrix containing the variance for the differences between the first genotype and the second (d_1) and between the first and the third genotype (d_2). Thus

$$\mathbf{K'GK} = \begin{bmatrix} Var_{d1} & Cov_{d1,d2} \\ Cov_{d1,d2} & Var_{d2} \end{bmatrix} = \begin{bmatrix} 1 & 0.5 \\ 0.5 & 1 \end{bmatrix} \frac{2}{n_e} \tag{5}$$

If the experiment is balanced with regard to genotypes **K'GK** is always a symmetric matrix with equal variances and equal covariances resulting from the equal number of groups for all hen lines. In a completely randomised and balanced design (with only μ and h_1, h_2 and h_3 as effects) each variance would be equal to $2/n_e$, where n_e is the number of observations per hen line, and all covariances would be equal to n_e. In the designs considered here a constant $2/n_e$ can be factored out of **K'GK**, leading to a correlation matrix with all correlations equal ½ (see the appendix for the only exception D3, which is slightly unbalanced). By transforming

$$Var_{d1} = \frac{2}{n_e} \qquad \text{to } n_e = \frac{2}{Var_{d1}} \tag{6}$$

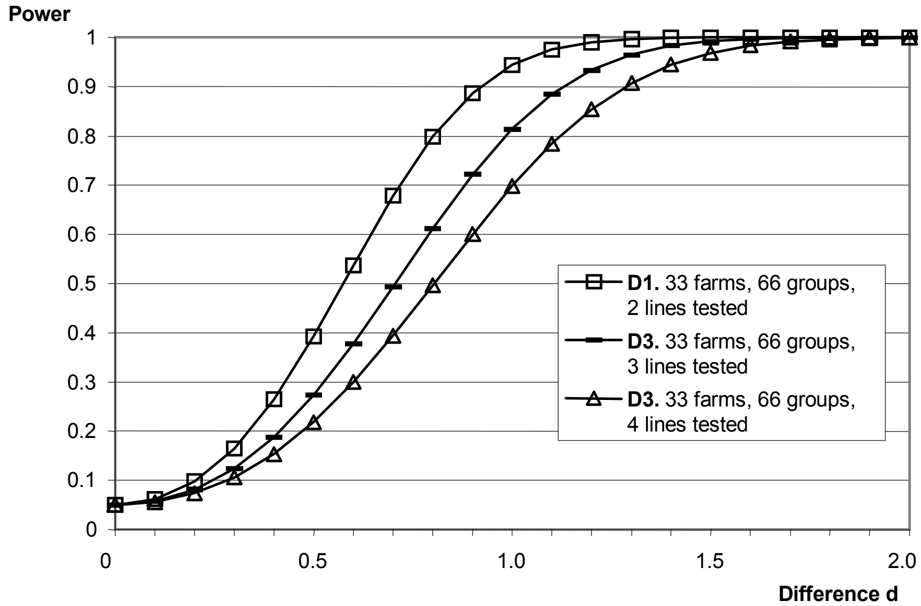
we can calculate the effective number of observations, i. e. the number of observations per hen line in a balanced completely randomized design, that would yield the same experimental power as one of our particular block designs, when an F-test with denominator degrees of freedom n_e minus the number of hen lines is used. Designs were also compared with respect to the ratio n_e/n_a where n_a is the actual number of observations per line. The maximum value of this ratio a particular design can have is one, indicating maximum relative efficiency, while values lower than one denote loss of efficiency e.g. because of incompleteness of blocks. All calculations were done by repeated runs of an own program using the IML-procedure of the SAS® software (SAS Institute Inc.,© 2002 - 2003).

RESULTS

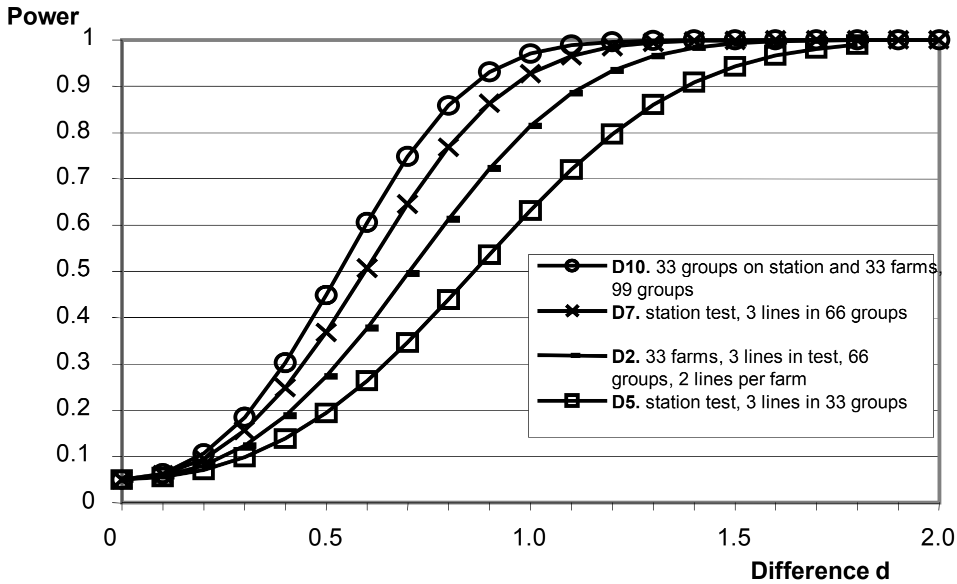
Power curves for various experimental designs are depicted in figure 1. Comparisons of two, three and four genotypes on 33 farms with two groups each (D1 to D3, figure 1a) exhibit a decline of experimental power with increasing number of genotypes. With three lines and a difference of $d = 1$, power was approximately 80%; with four lines this value dropped by 10% and reached only 70% (see also table 1). The ratio between the effective number of groups n_e and the actual number n_a per line was n_e/n_a=0.67 with four genotypes, i.e. the number of groups has to be increased by 50% in comparison to a trial, where all groups are housed on a single station (1/0.67 = 1.50). The ratio n_e/n_a was improved to a value of 0.75 for design D2 with three genotypes and even better for D1, a complete block design (RASCH et al., 1992) with only two genotypes, where n_e/n_a equals 1, which means full equivalence to a completely randomised design.

Figure 1, Panel a-e: Power analyses for various experimental designs of tests in station, field and combinations. The difference d between lines is measured in standard deviations.

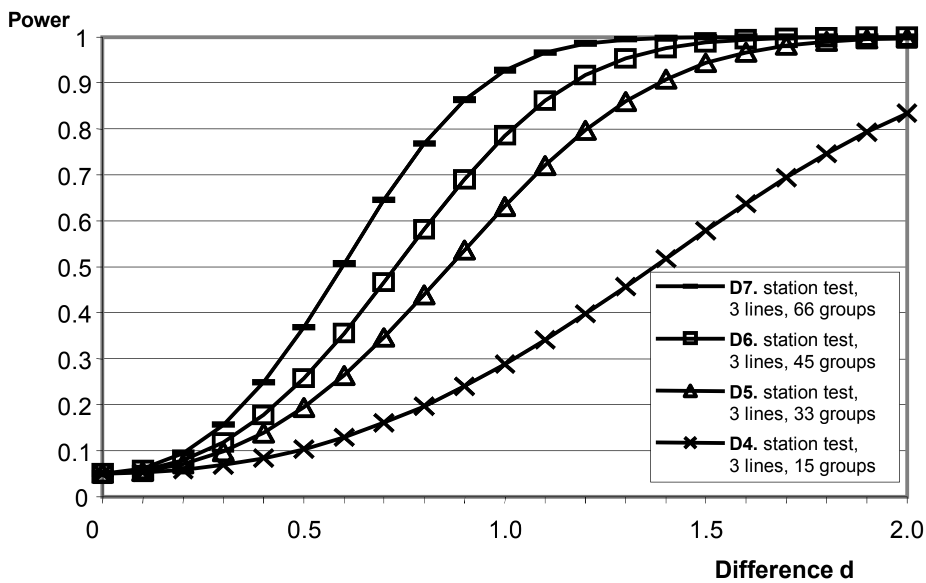
a)



b)



c)



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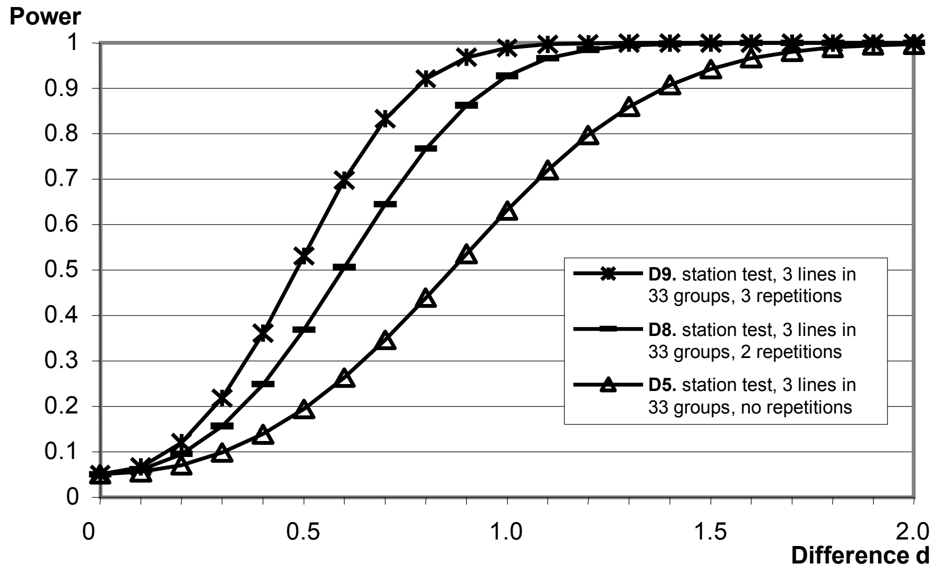

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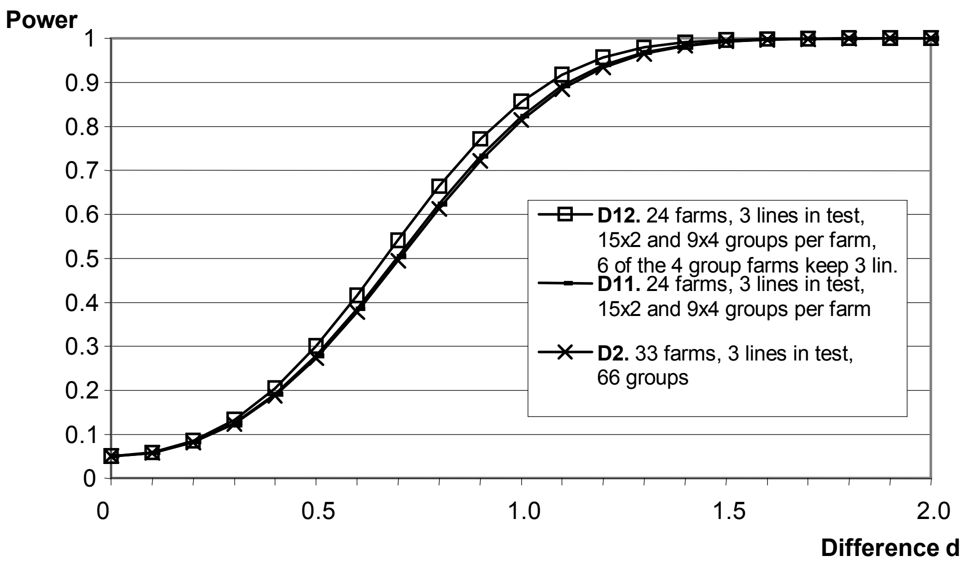


The better efficiency of an on-station evaluation of lines in terms of experimental power is exemplified by comparing D7 and D2 (figure 1b), both with 66 groups either on station (D7) or on-farm (D2). In the range between d = ½ to d = 1 the difference in power is in a magnitude of 10% or more, due to the reduced n_e/n_a-ratio of 0.75 with three genotypes, which indicated that four groups on farm are equivalent to three groups on station under the given assumptions.

For some traits, e.g., feed conversion, scenarios with on-station testing only are relevant due to the difficulty to record these traits under practical field conditions. Power curves for such designs are shown in figure 1c. At first glance a low-cost design (D4) with 5 groups per genotype - the minimum requirement according to the recommendations given in LAUPRECHT et al. (1973) - is not sufficient; in order to achieve 80% experimental power a difference d as large as two standard deviations is necessary. In order to reach 80% power for d = 1 standard deviation 15 groups per genotype (D6) are required, the upper limit of the aforementioned recommendation. With three lines this would require the total test capacity of the test-station in Kitzingen. With only few less groups (11groups per line, D5), the power drops to 64% at d = 1. A need for higher experimental power therefore requires additional test capacity either on a second station (Haus Düsse) or a repeated run in Kitzingen (e.g. D7, figure 1c) and D5, D8, D9, figure 1d) for those traits, which cannot be recorded on practical egg-producing farms.

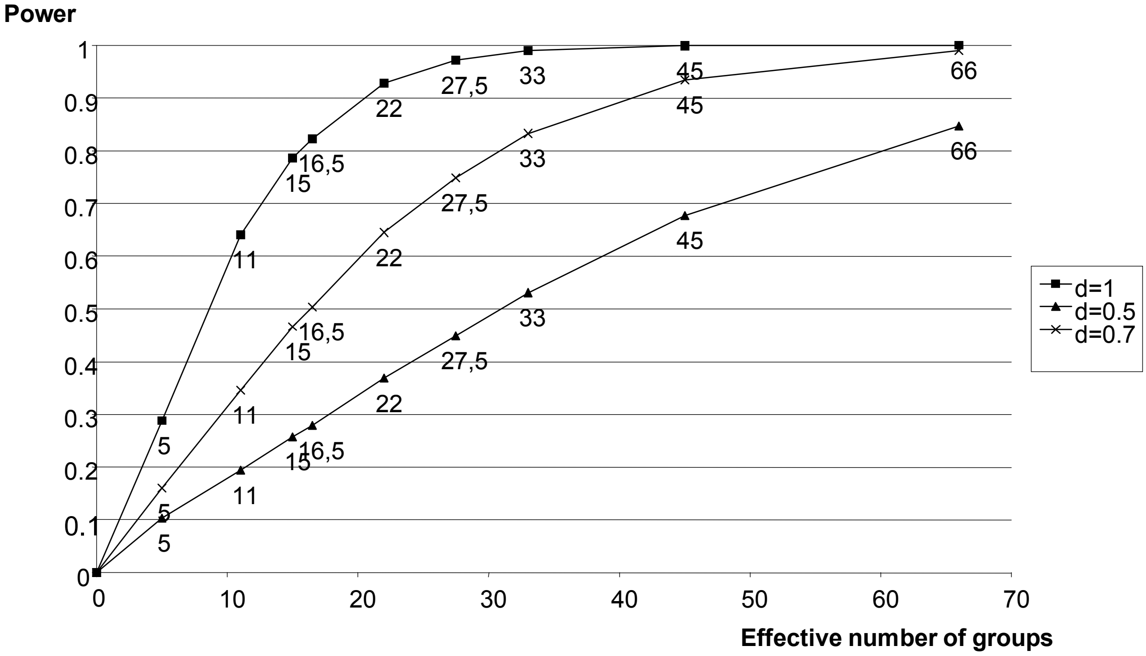
The effect of combining on-farm and station test for experimental power is illustrated in figure 1b, where designs D2 with 66 groups on farms and D5 with 33 groups on station were fused into the combined design D10, where 80% power can be achieved with a d-value of approximately 0.75. Since part of the traits will be recorded on station only, even more groups on station would be desirable for those traits, as in design D6 (figure 1c) with 45 groups on station. The inverse of the ratio n_e/n_a is 1/0.83 = 1.20, which is considerably better than in pure on-farm testing scenarios with more than two genotypes, e.g. D2, because the total number of groups has to be increased by 20% instead of 33%, compared to a completely randomised design on station or a complete block design.

Figure 1e is devoted to the question, how groups should be allocated to farms, namely the effect of having four groups on some of the farms (D11 and D12) versus only two groups on all farms (D2). The result is that power could be considerably increased if on the four-group-farms more than two different genotypes are recorded. The ratio n_e/n_a was 0.82, which is almost as good as in the combined field and station testing design D10, where one third of the groups are allocated to station and two third to farms with only two groups each. It should be emphasised that this relatively favourable n_e/n_a ratio came along with only six farms keeping all three genotypes in four groups (e. g. AABC, see also table 1).

If, as expected from practical experience of the authors, it turns out to be difficult to recruit farms with more than two genotypes for participation, then the comparison of D2 and D1 in figure 1e shows that only the total number of groups on farm matters, but not their distribution on farms with two or four groups. Both D11, where 15 farms keep two and nine farms keep four groups, and D2, where all farms keep two groups, yield the same n_e/n_a ratio of 16.5.

The results from different designs with three genotypes are summarised in figure 2, showing the dependence between experimental power and the effective number of groups in the trial. For a difference of d = 1 a power of 80% is already reached with approximately 16 effective groups per line, for d = 0.7 more than 30 effective groups are needed and if d equals 0.5 more than 60 effective groups per genotype would be required.

Figure 2: Power of statistical tests depending on the effective number of groups n_e



DISCUSSION

Among the underlying assumptions for all calculations was that only one line differs by d standard deviations from all others. With three or four genotypes the resulting power is higher, compared to the worst case, where two lines differ by the same amount in positive and negative direction from the third line. For two genotypes there is, of course, no such difference. In order to maintain the number of different scenarios to be evaluated at a reasonable level, the authors tailored all calculations to the ability of different designs to reveal if one of the tested lines exhibits special characteristics compared to all others. Since the number of different genotypes is limited, results for other assumptions on the non-equivalence of genotypes are expected to be similar and can easily be investigated with the same methods.

Practical experiences showed that organic egg producers only use 6 to 7 different hen lines more frequently. Therefore a comparison of three lines would already cover approximately 50% of the spectrum of the commercially important genotypes for organic egg production. Experiments in which two lines representing well-known layer hybrids are compared with an additional line with more or less unknown characteristics can be organised with sufficient power. The inclusion of farms with more than two contemporary groups may be convenient, since experimental power is not affected when the total number of farms is easier to coordinate. A desirable increase of the effective number of groups, however, could be achieved if such farms with more than two groups would keep more than two different lines. In order to achieve this, sufficient preparation time would be required for detailed agreement between egg-producing farms, farms raising the young hens and suppliers of chicks. In the light of our results it would, however, be worthwhile to reconcile all participating parties in order to make the experiment more effective, even if only some of the farms would keep more than two genotypes.

The absolute magnitude of a standard deviation for particular traits may be taken from the literature, when the sufficiency of an experimental plan has to be judged prior to running the experiment. FLOCK ET AL. (2003) found a somewhat increased variability in floor housing and with untrimmed beaks compared to cage housing and trimmed beaks, which can be also be expected for organic production conditions. Standard deviations were 9.4 % in laying performance per average hen, 0.097 kg per kg egg mass in feed conversion and 0.73 g in egg weight. Mortality rates had standard deviations of 9.9 % in natural death rates and 9.4 % in mortality by cannibalism. Values for the variability of traits should therefore preferably be taken from experiments where conditions for organic egg-farming were met.

A combined evaluation of genotypes on station and on a sufficient number of farms offers extra opportunities compared to a test in a single environment. First of all, station testing provides the possibility to record traits which cannot be recorded under practical conditions. Second, a comparison of environments enables a test for genotype-environment interactions, which have been assumed to be absent in all our calculations. If they prove to be significant for some traits, it may be possible to identify their origin, especially when information on farm-size, production level, feeding regimen, parasitic load and other potential causes are carefully collected in addition to the performance traits of interest. Such parameters suitable for specifying the characteristics of the participating farms are also of value when the validity of the results for other farms which were not in the experiment has to be assessed.

The effective number of groups is recommended to be calculated before an experiment is run in practice in order to ensure sufficient experimental power. When the size of n_e is known, it can be used to calculate the power by using available software (e. g. CADEMO©, G*Power©, piface.jar©) for a completely randomised design with n_e groups per line, or, even simpler, by using the graphic of figure 2 for a rough check.

In practice relative efficiencies of designs may be affected by additional factors, among them inhomogenity of variances and genotype-environment interactions. Keeping this in mind, we may conclude that for a comparison of more then two genotypes under field conditions the number of groups per line has to be increased by 33% to 50% in order to maintain the same level of experimental power as in a completely randomised experiment on a single test station or with two genotypes in the field. The amount of the necessary increase is higher for a larger number of genotypes. Therefore i) the number of different genotypes should be restricted to three, at most four in the light of the available test capacity in Germany. ii) With two genotypes on each farm the number of groups per farm (two or four) does not affect power for a given experimental size. iii) Loss of efficiency (in terms of effective number of groups) can be limited by either keeping more than two genotypes on at least part of the farms or by combining evaluation under station and field conditions for traits lacking genotype-environment interactions.

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APPENDIX

The effective number of groups per line in unbalanced designs can be derived from the determinant of $\mathbf{K'GK}$. When the design is balanced with regard to lines the matrix $K'GK$ is

$$\mathbf{K'GK} = \begin{bmatrix} 1 & \frac{1}{2} & \cdots & \frac{1}{2} \\ \frac{1}{2} & 1 & & \frac{1}{2} \\ \vdots & & \ddots & \vdots \\ \frac{1}{2} & \frac{1}{2} & \cdots & 1 \end{bmatrix} \cdot \frac{2}{n_e}$$

and the determinant of $\mathbf{K'GK}$ can be written as

$$\left(\frac{2}{n_e}\right)^2 \cdot \left(\frac{1}{2}\right)^{d-1} \left(d\frac{1}{2} + \frac{1}{2}\right) \cdot \sigma_e^2,$$

where d is the dimension of $\mathbf{K'GK}$ (number of lines minus one), n_e is the effective number of groups per line as defined above and σ_e^2 is the residual variance. The latter formula is based on the fact that, according to HARVILLE (2001) the determinant of a symmetric matrix $\mathbf{A}$ with diagonal elements $x+1$, off-diagonal elements x and dimension d can be expressed as

$$|\mathbf{A}| = \lambda^{d-1}(dx + \lambda)$$

The effective number of groups per line then becomes

$$n_e = 4 \cdot \sqrt{\left(\frac{|\mathbf{K'GK}|}{c \cdot \sigma_e^2}\right)^{-1}}$$

where $c = \frac{3}{4}$ and $c = \frac{1}{2}$ for 3 and 4 lines, respectively.

This way of computing n_e can also be used for unbalanced designs (e.g. group numbers 16, 16, 17 and 17 per line in design D3) in order to obtain a „mean“ n_e, which can can be related to the mean actual number of groups (e.g. 16.5).

SUMMARY

Comparisons of commercially available layer hybrids have become short of capacity in Germany. On-farm testing could relax this shortage and provides the possibility to compare genotypes under practical production circumstances, whereby organic farming is of growing importance for consumer egg production. For a number of different experimental designs – station test, on-farm test and combined – the experimental power to detect line-differences was evaluated using an F-test for the global null-hypothesis of equality of all lines. Efficiency of designs was compared relatively to a completely randomized design. Since organic farms typically are small, farms were treated as (incomplete, with more than two genotypes in the experiment) blocks providing two observations (two groups of different genotype) or, in some cases, four observations.

A main result was that a comparison of three (four) lines requires 33% (50%) more groups per line than an experiment with two genotypes in order to achieve equivalent experimental power. Therefore the number of different genotypes should not exceed three or, at most, four. When only two different genotypes kept on each farm the number of groups per farm - two or four - does not affect power for a given experimental size. Loss of efficiency due to incompleteness of blocks can however be limited by keeping more than two genotypes on part of the farms, which may be difficult to organize, or by a combined evaluation under field and station conditions.

Despite of some probably simplifying assumptions results may serve as a guideline for organizing such experiments in the future.

Keywords: laying hen, performance test, experimental design, experimental power

ZUSAMMENFASSUNG

Für den Vergleich kommerzieller Legehennenherkünfte ist die Prüfkapazität in Deutschland knapp geworden. Herkunftsvergleiche auf praktischen Betrieben könnten diesem Engpass abhelfen und bieten einen Vergleich unter tatsächlichen Produktionsbedingungen, wobei der Erzeugung von Konsumeiern im ökologischen Landbau eine steigende Bedeutung zukommt.

Für eine Reihe von Versuchsplänen – Stationsprüfung, Feldprüfung auf Betrieben und deren Kombination – wurde die Güte hinsichtlich der Aufdeckung von Linienunterschieden mittels eines globalen F-Tests für die Nullhypothese der Gleichheit aller Linien untersucht. Da ökologische Betriebe typischerweise eher klein sind, wurden Betriebe als (bei mehr als zwei betrachteten Genotypen unvollständige) Blöcke behandelt, mit im Regelfall zwei Beobachtungen (zwei Gruppen mit unterschiedlichem Genotyp) oder in einigen Fällen auch vier Beobachtungen.

Ein Hauptergebnis war, daß für einen Vergleich von drei (vier) Linien eine um 33% (50%) höhere Anzahl von Gruppen benötigt wird als beim Vergleich von nur zwei Linien, wenn eine gleichwertige Güte erreicht werden soll. Die Anzahl der Linien in einem Vergleichstest sollte deshalb drei, allerhöchstens vier, nicht übersteigen. Die Gruppenzahl je Betrieb – zwei oder vier - hat keinen Einfluß auf die Güte bei konstanter Gesamtanzahl von Gruppen, wenn auf jedem Betrieb jeweils nur zwei verschiedene Genotypen gehalten werden. Ein Effizienzverlust durch die Unvollständigkeit der Blöcke kann aber begrenzt werden, wenn ein Teil der Betriebe mehr als nur zwei verschiedene Herkünfte hält, was vermutlich nicht leicht zu realisieren ist, oder wenn Stations- und Feldprüfung kombiniert werden.

Trotz einiger möglicherweise vereinfachender Annahmen können diese Ergebnisse als Richtschnur für die Durchführung solcher Experimente in der Zukunft dienen.

Stichworte: Legehennen, Leistungsprüfung, Versuchsplanung, experimentelle Güte

CHAPTER THREE

A Station Test of Four Laying Hen Hybrids under Semi-Organic Conditions –Laying Performance, Feed Conversion, Egg Quality, Mortality and Plumage Condition

Eine Stationsprüfung von vier Legehennenhybriden unter semi-ökologischen Bedingungen – Legeleistung, Futterverwertung, Eiqualität, Mortalität und Gefiederzustand

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INTRODUCTION

During recent years consumer interest on welfare of food producing animals in Germany has increased (HÖRNING, 2003). As a result, organic egg production has proliferated (RÖHRIG and BRAND, 2005) and more consumers show a preference for healthy animals in production. In order to meet consumer demand, robust breeds for alternative and organic housing systems are required (BRADE, 2000). In spite of the increasing production in floor and free-range housing and organic systems (JACOBS and WINDHORST, 2003) laying hen farmers still have difficulties finding and selecting suitable breeds for their production systems as there is no independent performance test system in Germany.

Therefore, a study was initialized to plan and conduct a laying hen performance test on practical organic farms (GLAWATZ et al., 2007, GLAWATZ et al., 2009). As a part of this study tests on two stations were conducted as some traits, such as egg quality and feed conversion, only very hardly and with great costs can be determined properly under farm conditions.

This paper presents the results for laying performance, egg quality, feed conversion, mortality rates and plumage condition of four brown egg layer hybrids on the test stations, with special emphasis on the effects of hybrid and station.

MATERIALS AND METHODS

Experimental Design

For the performance test the four brown hybrids ISA Warren (ISA), Tetra SL (TB), Lohmann Brown (LB) and Lohmann Tradition (LT) were chosen. They were tested in the German test stations in Kitzingen (Station 1) and Haus Düsse (Station 2). The stations, which are build for tests under conventional conditions without free range, adapted their facilities as good as possible according to the European Guidelines for Organic Production (BMELV, 2008). In contrast to former official station tests, all hens were hatched and reared in Station 1. According to organic requirements they were not beak-trimmed. During the laying period they were housed at a stocking density of 6 hens per m^2 in all facilities and were fed organically produced food. No additional corn for activity in litter areas, as it is required by some organic associations in Germany, was given. In Station 1, the hens had floor pens with one third of the floor covered with wooden shavings and a raised (ca. 50 cm) floor covered with plastic slats for the rest of the pen. Birds were housed in groups of 25 hens per pen and 11 groups per hybrid line. The facilities in Station 2 provided two different housing systems. In the first system, four large 220-hen groups were kept in a floor system with slat covered manure boxes and a sand winter garden, two with ISA W and two with LB. The remaining hens were kept in

24 small groups in furnished cages (Eurovent 625). There were 12 groups of ISA and 12 groups of TB hens divided into three groups each of 10, 20, 40 and 60 hens. Thus three distinct housing facilities could be tested.

The laying period was defined as 364 days of lay starting in January 2007 when the hens were at 20 weeks of age. The investigated traits can be grouped into laying performance and egg number, feed conversion, egg quality (albumen height and breaking resistance, as given by both stations), mortality (natural and cannibalistic causes) and plumage condition. The number of floor eggs was evaluated for Station 1 and for floor housing in Station 2; for small group housing no misplaced eggs were recorded. Plumage condition was evaluated by a reduced feather condition scoring (FCS) version of the "LayWel" scoring system (TAUSON et al., 2003), developed in order to reduce stress to the birds and increase scoring efficiency. A detailed description and comparison of both scoring systems and their influence on stress levels is given in KJAER et al. (2008). In brief, the full LayWel scoring evaluates plumage condition of 6 body parts: neck, back, wings, tail, breast and cloaca. A score from four points (very good plumage) to 1 point (very damaged plumage) is given to each body part while handling birds individually. In contrast to this intensive scoring, hens in the present study were scored without catching and only the body parts neck, back, wings and tail were scored

Statistical Analysis

The basic model applied to for all traits was the following using l_i for the fixed effect of hybrid line (i=ISA, LB, LT or TB), s_j for the fixed station effect (j=1, 2 or 3; 1= Station 1, 2=Station 2, floor housing and 3=Station 2, small groups) and e_{ijk} as random residual. For laying performance traits (y) such as rate of lay and egg number, egg weight, egg size and egg mass and for mortality and plumage condition the impact of group size within station $gs(s)_{jk}$ (k=10, 20, 25, 40 or 60) was added as a third fixed effect.

$$y = \mu + l_i + s_j + gs(s)_{jk} + e_{ijk}$$

Egg quality was analyzed concerning the effects of line, station and date of data collection d_l (First, sixth and 12th four-wk-laying period, l=1, 2, 3) by the model

$$y = \mu + l_i + s_j + d_l + e_{ijl}$$

In computation of effects on feed conversion (y) the period of data collection (four wk laying period, lp_m (m=1 to 13) and again group size within station $gs(s)_{jk}$ were added in the basic model. The effect of group g_n (n=1 to 72) was included as a random effect to take correlations between repeated measurements within groups (autoregressive correlation structure) into account.

The model for feed conversion was

$$y = \mu + l_i + s_j + lp_m + gs(s)_{jk} + g_n + e_{ijkm}$$

All traits were statistically evaluated by the GLIMMIX procedure of the SAS ® software (SAS INSTITUTE INC., © 2002-2003). Data are presented for line differences and station differences as Least Squares Means (LSM) ± Standard Error (SE). Significant effects were further analyzed using post hoc tests with tukey-adjustments for multiple comparisons. Means followed by different superscript letters are significantly different at $p \leq 0.05$.

For this test of 72 hen groups in three different facilities with a minimum detectable line difference of 1 standard deviation and an alpha error of 5 %, the power 1-β was calculated as 88.22 % (GLAWATZ et al., 2009). Homoscedasticy was assumed.

RESULTS

As shown in Table 1, the hatching rate differed depending on the line. LB had the highest percentage of hatched chicks; over 80% of eggs inserted into the hatching machine hatched. In percentage of hatched chicks of the fertilized eggs TB was the best line. Again in the number of inserted eggs per female chick the LB performed best; they needed the lowest number of eggs to get a female laying hen. They also reached the highest body weight for beginning of lay, had the lowest mortality and the lowest number of eggs per hen until day 140.

Table 1: Results for hatching and rearing of all hens in Station 1.

	Hatching				Body weight		mortality		Eggs per hen
Hybrid	of inserted eggs %	of fertilized eggs %	of female chicks %	eggs per female chick pcs.	week 8 g	week 20 g	week 8 %	sum %	Until 140th day pcs.
LB	80.3	86.3	49.4	2.5	621	1622	1.1	1.1	0.23
LT	76.3	84.6	49.6	2.6	612	1575	1.6	1.6	0.47
TB	75.6	88.6	49.0	2.7	633	1554	0.8	1.1	0.43
ISA	74.7	83.9	49.9	2.7	613	1563	1.7	1.7	0.29

The start of lay, given as the third day in series of over 50% of lay, differed significantly between all test facilities and between all hybrids. Start of lay LS-means were between day 153 for LT hens and day 155 for ISA hens. The stations had values of 154 days for Station 1, 155 days for Station 2, floor housing and 153 days in Station 2, small group housing. The differences between the hybrids concerning laying performance, egg number and mortality are shown in Table 2.

Table 2: Laying performance, egg number and mortality of the four hybrids.

	ISA		LB		LT		TB	
Trait	LSM	SE	LSM	SE	LSM	SE	LSM	SE
Laying performance per housed hen (%)	73.8^{a}	1.33	78.6^{a}	1.71	78.1^{a}	2.03	72.6^{b}	1.51
Laying Performance per population hen (%)	81.1^{b}	0.96	85.1^{a}	1.25	$81.6^{a,b}$	1.48	77.1^{c}	1.09
Egg number per housed hen	$269.0^{a,c}$	4.83	$286.1^{a,b}$	6.26	$284.3^{a,c}$	7.41	264.5^{c}	5.49
Floor eggs (%)	3.4	1.44	5.1	1.44	1.4	1.74	5.4	1.74
Mortality (%)	20.3	2.27	14.3	2.93	12.2	3.48	16.1	2.58
Cannibalism (%)	7.8	1.33	6.5	1.73	6.6	2.05	6.7	1.52

TB hens had the lowest laying rate per housed hen and per hen day. As LT hens had lower mortality rates they performed almost as well as LB concerning laying rate per housed hen and egg number, but could not reach the same level as LB in laying rate per population hen. The ISA hens had lower production than LB and LT hens but higher than TB. The hybrids did not differ significantly in the percentage of floor eggs, which was between 1.41 and 5.4 %.
For all other laying performance traits line differences were significant. The effects of station and group size within station, if estimable, were not significant. Total mortality levels (Table 2) differed between 12.19 and 20.33 % without reaching significance. Again LB and LT hens performed best. LS-Means for mortality caused by cannibalism were similar between the hen hybrids (Table 2). Further analyses for effects of station and group size showed that cannibalism was very low in Station 1 (0.64 %) but higher in Station 2 (11.24 % in floor housed 220-hen groups and between 3 and 14.1 % in 10-hen and 60-hen groups, Table 3).
The rate of cannibalism increased with the number of hens in small groups (3.0 % in 10-hen, 8.0 % in 20-hen, 10.1 % in 40-hen and 14.1 % in 60-hen groups, SE=2.39). The group size within station was significant for cannibalism. The effect of line was not significant in this case, but a highly significant effect of station could be observed.

Table 3: Laying performance, egg number and mortality in the three station facilities

	Station 1 floor		Station 2 floor		Station 2 small groups	
Trait	LSM	SE	LSM	SE	LSM	SE
Laying performance per housed hen (%)	77.3	0.83	73.9	2.83	76.2	1.37
Laying performance per hen day (%)	82.6	0.60	79.2	2.05	82.0	1.00
Egg number per housed hen	281.5	3.01	269.2	10.31	277.3	4.99
Floor eggs (%)	5.8	0.65	1.8	2.24	-	-
Mortality, overall (%)	11.9	1.41	18.3	4.84	17.0	2.34
Mortality from cannibal-ism (%)	0.6^{b}	0.83	11.2^{a}	2.85	8.8^{a}	1.38

In Table 4 the average egg weights are displayed; with 60.3 g the ISA hens had the lowest value for this trait. Again the LB and LT hens had the highest values with 63.0 g for LB and 63.3 g for LT. TB hens were slightly lower (62.0 g).

A similar ranking could be observed for egg mass production per hen, the ISA hens had the smallest value. LB and LT hens had similar results and TB had results between ISA and Lohmann hens. Feed conversion was significantly affected by hybrid, station, group size within station and by date of analysis.

The percentage of eggs in different size classes showed a higher proportion of smaller eggs (size M) for ISA and of bigger eggs of size L and XL for the LB and LT hens. TB performed again between ISA and Lohmann hens.

Table 4: Results of hybrids for mean egg weight, egg mass, feed conversion, egg sizes and egg quality traits

	ISA		LB		LT		TB	
Trait	LSM	SE	LSM	SE	LSM	SE	LSM	SE
Average egg weight (g)	60.3^{c}	0.21	63.0^{a}	0.27	63.3^{a}	0.32	62.0^{b}	0.24
Egg mass per population hen (kg)	17.6^{b}	0.42	19.6^{a}	0.55	19.4	0.64	18.6	0.48
Feed conversion (kg/kg)	2.4^{b}	0.03	2.2^{c}	0.05	2.2^{c}	0.05	2.4^{a}	0.03
XL-eggs (%)	2.9^{c}	0.24	5.2^{a}	0.27	5.8^{a}	0.30	4.3^{b}	0.26
L-eggs (%)	30.3^{c}	0.75	45.0^{a}	0.87	46.6^{a}	0.97	38.7^{b}	0.83
M-eggs (%)	50.9^{a}	0.93	40.6^{c}	1.08	38.6^{c}	1.21	44.0^{b}	1.04
S-eggs (%)	11.6^{a}	0.49	4.5^{c}	0.56	4.8^{c}	0.63	9.0^{b}	0.54
Cracked eggs (%)	$0.28^{a,b}$	0.09	0.5^{a}	0.11	0.1^{b}	0.12	0.1^{b}	0.10
Wind-/Broken eggs (%)	2.9	0.13	2.9	0.15	2.8	0.17	2.8	0.15
Breaking resistance (N)	40.1^{b}	0.49	43.7^{a}	0.66	$43.0^{a,b}$	0.96	$42.1^{a,b}$	0.66
Albumen height (HU)	85.6^{b}	0.60	87.3^{b}	0.81	90.7^{a}	1.17	84.6^{b}	0.81

The percentage of cracked and broken eggs was relatively low; with TB hens showing the best results (see Table 4). In contrast, the breaking resistance of LB eggs was higher than that of TB hens. Albumen height was best in LT. All traits except the percentage of broken eggs had significant differences between hybrids and between stations as well as between dates of investigation. Group size within station had significant effects on egg weight, egg mass, feed conversion, XL-eggs and broken eggs (Table 5).

Table 5: Results of stations for mean egg weight, egg mass, feed conversion, egg sizes and egg quality traits

	Station 1 floor housing (25 hens)		Station 2 floor housing (220 hens)		Station 2 small groups (10 to 60 hens)	
Trait	LSM	SE	LSM	SE	LSM	SE
Average egg weight (g)	60.9[c]	0.13	63.5[a]	0.45	62.0[b]	0.22
Egg mass per population hen (kg)	18.2[b]	0.26	18.6[a,b]	0.90	19.8[a]	0.44
Feed conversion (kg/kg)	2.5[a]	0.10	-	-	2.2[b]	0.02
XL-eggs (%)	2.4[c]	0.11	6.8[a]	0.53	4.4[b]	0.28
L-eggs (%)	27.9[b]	0.35	48.5[a]	1.67	44.1[a]	0.89
M-eggs (%)	59.8[a]	0.44	31.3[c]	2.08	39.5[b]	1.11
S-eggs (%)	9.2	0.23	6.7	1.01	6.6	0.58
Cracked eggs (%)	0.8[a]	0.048	-	-	0.1[b]	0.11
Wind-/Broken eggs (%)	0.00	0.0	5.1	0.70	3.6	0.54
Breaking resistance (N)	41.1	0.43	42.8	0.70	42.9	0.70
Albumen height (HU)	86.2	0.52	87.5	0.86	87.6	0.86

Plumage condition of the four hybrids did not differ significantly. The average scores were between 2.9 and 3.3. Group size within test facility had no effect either. In contrast a significant difference between test facilities could be proven for average scores of body parts except for the neck. The values for the different types of housing are presented in Table 6.

Table 6: Plumage condition in the three test facilities of the two stations and percentages of affected animals per facility

	Station 1 floor housing (25 hens)			Station 2 floor housing (220 hens)			Station 2 small groups (10 to 60 hens)		
Trait	LSM	SE	%	LSM	SE	%	LSM	SE	%
Plumage neck	3.2	0.07	21.3	2.6	0.24	34.0	3.1	0.12	21.8
Plumage back	3.9[a]	0.06	3.5	2.2[c]	0.21	46.0	2.9[b]	0.10	28.8
Plumage wings	3.9[a]	0.05	2.5	2.6[c]	0.16	35.3	3.3[b]	0.08	17.8
Plumage tail	3.9[a]	0.06	2.5	2.2[c]	0.21	46.3	3.0[b]	0.10	25.0
Total Score	3.7[a]	0.06	7.5	2.4[c]	0.19	40.5	3.1[b]	0.09	23.3

Feather pecking behavior spread rapidly in the floor system of Station 2. In Station 1, almost no plumage losses were observed.

DISCUSSION

The modern laying hen farmer uses commercial hybrids in all housing systems. Breeding companies provide special breeds for different housing systems, as can be seen in their product descriptions. For brown-egg production in alternative systems, specialized hybrids (e.g. ISA Warren) are offered, which are used as well as all other brown egg layer types. Comparisons of hybrid and pure bred hens showed that organic farming still requires hybrid hens to reach an economic level of production (MÜLLER et al., 1999).

As declared by their breeding companies the 4 hybrids used in this study are well suited for alternative and organic housing conditions (ISA, LB and LT) and smaller flocks (TB) (HENDRIX GENETICS, 2008; LOHMANN TIERZUCHT GMBH, 2008a; LOHMANN TIERZUCHT GMBH, 2008b; BÁBOLNA TETRA GMBH, 2008). The declarations state minimum egg numbers of 287 (ISA), 305 (LB), 290 (LT) and 311 eggs (TB) per hen housed in 364 days of lay, respectively, which was not reached by the four hybrids in this test. In comparison, other studies using conventional housing systems showed higher and lower performances (VITS, 2005; ABRAHAMSSON and TAUSON, 1995). This variation is due to different management and feeding conditions and may also be influenced by genetic improvement of hybrids over time. Nevertheless ISA W, LB and LT were able to have egg numbers of 269, 286 and 284 eggs in 364 days of lay which is remarkably similar to performance indicated in the breeders' declaration. Although TB hens were declared to have a higher performance than all other hybrids, they performed worst with 264 eggs in 52 weeks of lay. This also applies to percentage of laying performance. The results of studies with conventional housing systems differ concerning ranking of hen hybrids (VITS, 2005; ABRAHAMSSON and TAUSON, 1998) in part due to lower performance level of LB in those studies compared to the present results.

The percentage of floor eggs, which was measured in floor housings systems, was between 1.41 and 5.4 % with no significant effects of line and station. Floor eggs mean a higher percentage of dirty eggs and a higher amount of work to collect them. They also have a big practical relevance as normally under practical conditions nest-space is as small as possible and thus has to be used to full capacity. Although statistical significance of line differences could not be proven, the differences in values obtained should not be disregarded.

Other studies reported higher performances under conventional conditions for LB hens than for LT hens, with a difference of 3.5 % per housed hen and 4.6 % per average hen (LEBRIS, 2005). DAMME (2003) compared test results from Station 1 and 2 and from a third station (floor housing) using non-beak trimmed hens. He found a higher number of eggs per hen for LT in comparison to TB hens.

A significant effect of station on laying performance could not be found in the present study. This is surprising, as enriched cages are supposed to provide higher performances than alternative systems (LAYWEL, 2006). Animal welfare is supposed to be good in enriched cages (MOESTA et al., 2007) and, in contrast to aviary systems, the risk of management effects on welfare and performance is low (BUCHENAUER, 2005).

Average egg weights differed significantly between hybrids and between stations. The difference between LB and LT was marginal and the means were below those declared by the breeders. The latter case was the same in ISA W and TB; their average egg weights were slightly below those declared. The differences between declarations and present results, as well as between stations, may be explained by different feeding regimes containing higher rates of oil seeds as a protein carrier (ANDERSSON et al., 2006) or higher rates of low-energy components (WAHLSTRÖM et al. 1998). The effect of group size within station also had a statistical impact on egg weight which can be explained by the development of egg weight during one year of lay. Higher average egg weights for LT hens were also reported by LEBRIS (2005). This is similar to the results for egg sizes in this study as LB and LT had the highest rates of L-size eggs, they did not differ significantly. They were followed by TB, whose difference to the other hybrids was significant. ISA hens seem to be bred for smaller egg sizes as they had significantly higher rates of M-size eggs.

Feed conversion was between 2.18 (LT) and 2.44 (TB) kg feed per kg egg mass. Again the TB hens had the lowest performance. Feed conversion was significantly affected by hybrid line as well as by station, group size within station and date of analysis. The effect of station and group size can be explained by different group sizes within different housing types (floor and small group housing). This was supported by ELSON and CROXALL (2006) and VAN HORNE and VAN NIEKERK (1998), who found higher feed intake rates in alternative systems than those in cages.

Feed conversion improved with the start of production from the first to the second laying period. Values remained relatively constant throughout the laying year and worsened from the tenth laying month onwards. This shows that hens were not able to maintain a constant feed efficiency over the entire laying period.

For egg quality traits the differences between hen hybrids could be proved to be significant. This is comparable to BRESLAVETS (1995) who reported significance of line, age and housing conditions on egg quality. In the present study both breaking resistance and albumen height were not affected by station type, but was indeed affected by age of the hens. This in line with other results showing that egg shell quality as well as albumen quality decrease during the laying period (GRASHORN, 2008).

All hybrids had far higher mortality rates than those found in the breeders' declarations (4 to 6 %). Though the management conditions in the two test stations should present best case scenarios, overall mortality was between 12 and 20 %. Other studies show mortality rates of 3.47 % in conventional and organic free-range housing (LAMBTON et al., 2005), though this was not expected for all performance data collections, as the large effects of both farm and herd must be considered for practical data.

Among other reasons, the high mortality rates in this study might be due to sudden outbreaks of cannibalism in the floor housed and larger cage groups in Station 2, where the rates were calculated between 10.1 and 14.1 %. This phenomenon is also reported by other authors (ABRAHAMSSON and TAUSON, 1998).

Cannibalism is a widespread behavioral problem that can be induced or increased by high levels of severe feather pecking (KJAER and SOERENSEN, 2002) and that in general is believed to have several causes (BLOKHUIS et al., 2007a; YNGVESSON, 1997). Genetic differences between white and brown egg layers are well known (KJAER and SOERENSEN, 2002). Brown egg layers tend to show a higher proportion of cannibalism than their white counterparts. The outbreak of cannibalism in this study can only be explained by management factors, as there is no line effect measureable and only brown egg layers were used. This can be underlined by the observation that in spite of the same rearing conditions for all hens in the study problems with cannibalism as well as higher rates of feather pecking came up in Station 2. The occurrence of those problems was mainly in the middle of the laying period and may be ascribed to a poor feed supply, as reasons for aggressive pecking and cannibalism often lay in feeding inefficiencies. Analyses of feedstuffs considering their protein content showed that the variation of crude protein content within and between stations was quite high (21.0 % in station 1 (6^{th} month) and 19.1 % (6^{th} month) and 17.7 % (11^{th} month) in Station 2).

The effects of station and group size within station imply again that a large part of the losses due to cannibalism must be explained by feeding and light regime as well as by group size.

The effects of hybrid line, station and group size within station could not be proven as statistically significant for overall mortality. Nevertheless, line, station and group size differences were considerably high.

Feather pecking is a widespread problem in laying hens as ELLIOT (1996), BLOKHUIS et al. (2007a) and KREIENBROCK et al. (2004) showed. They stated that up to 40% feather loss in 72 week-old hens could be considered normal. Feather pecking is influenced by several effects, such as genetics (KJAER and HOCKING, 2004; SU et al., 2003), feeding (VAN KRIMPEN et al., 2005), group size (smaller is better) and stocking density (less is better) (BILÇIK and KEELING, 2000; COOK et al., 2006B; HIRT, 2004; LEBRIS, 2005). More and better structured free range reduces feather pecking (MAHBOUB, 2004; NICOL et al., 2003), but even in housing systems providing free range a feather pecking level of 37.3% was observed (LAMBTON et al., 2005).

In the present study plumage condition was recorded by a visual scoring system which was developed from the system of TAUSON et al. (2003). Animals were scored without being handled; this seemed to be the most appropriate technique for estimation of plumage condition by a single person without stressing the animals. Other technical systems, such as the use of an infrared thermograph (COOK et al. 2006a), would have been too work-intensive and expensive. The two systems are considered comparable as tested by KJAER et al. (2008, in prep.).

Though several studies showed genetic influences on feather pecking behavior, a significant difference between the four brown-egg layer hybrids tested in the present study could not be shown in this investigation. The results for plumage condition are not consistent with those of KJAER (2000) who compared the feather pecking activity of various brown hen hybrids and did not detect any acceptable line. In the present study, all 4 hybrids in Station 1 had very good plumage conditions, the higher percentage of featherless parts of the neck resulted from sharp edges of feeders rather then from feather pecking.

The comparison of plumage condition at different time points also showed that the head and neck region was affected more than the other parts of the body. Parallel to housing equipment, this might be due to an increase of aggressive pecking against compartment mates which reflects aggression rather than feather pecking. Feather pecking and aggressive pecking are considered having different physiological origin, as these two behaviors are shown to be differently affected by the treatment with haloperidol, a dopamine D2 receptor antagonist (KJAER et al., 2004).

Higher percentage of featherless body-parts in Station 2 (Tab. 6, averages of 34.0 to 46.3 %) could be explained by the significant effect of group size within station. Another effect for higher rates of feather pecking might be the absence of adequate access to litter (GUNNARSSON et al. 1999; GUNNARSSON et al. 2000) in Station 2, especially in small-group housing. Finally, outbreaks of feather pecking and cannibalism in Station 2 could be explained with stress through transport and changes in housing, climate and feeding. All birds were reared at Station 1 and so the birds for Station 1 had no transport.

An effect of station was statistically substantiated, which might again be explained by different feeding regimes. For organic feed used in a former performance test in Station 1, a better plumage condition than with conventional feeding was already reported by DAMME and TUTSCH (2008). The reason may be a very good reception of feed. The feed in Station 2 might have been imbalanced, which would have influenced feather pecking behavior (LEESON and WALSH, 2004). Feed conversion in Station 2 was significantly worse than in Station 1, therefore hens in Station 2 might have had difficulty satisfying their needs for special nutrients. As discussed above, feedstuffs often vary in ingredients, such as percentages of crude fiber or protein carrier plants. These ingredients have an effect on nutrient supply of hens and therefore on feather pecking as well as on cannibalistic behavior.

The results of this study displayed that performance of brown-egg hybrids under organic feeding and stocking densities can be appropriate for production if all management conditions are excellent. In practice, however, this is seldom the case. Summing up, a line effect on laying performance could be proven for all main traits except for broken eggs. The LB and LT hens performed best, followed by ISA Warren and TB. Mortality was highest in ISA hens, followed by TB, LB and LT. Of all mortality causes, 33 to 54 % were due to cannibalism, for which no line difference could be shown. No line differences could be detected for feather condition. On the other hand, a significant effect of station, group size within station and date of analysis could be shown for cannibalism and feather score on back as well as for egg weight, XL-eggs and egg mass. Only egg sizes L, M, S and cracked eggs were not influenced by group size, but by station and date. The station did not have a significant influence on egg quality traits.

It can be concluded that the differences between brown hen hybrids under organic conditions in laying performance traits are still considerable. The ranking of hybrids in the present study equaled well that given by the breeding companies except for TB hens. An effect of management, which is mainly based on feeding differences and group size, must be included for egg mass, egg size, feed conversion and cannibalism.

Though the results of this study showed that the station tested hen hybrids performed well under the tested semi-organic housing conditions, the problem of transferability of information from station tests for farm housing (smaller groups and intensive care, no free-range) to farm housing (larger groups, less intensive care, free-range) still exists. A need for information on suitability of hens for farm conditions with free-range housing and a variety of housing types is still given (PREISINGER 1997; PREISINGER et al. 1999; PREISINGER 2002) and further studies under those conditions will follow to supply the present results.

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SUMMARY

In spite of an increased market for eggs from alternative and organic production in Germany, problems with low performance and behavioral disorders such as feather pecking and cannibalism are still reported. A project was initialized involving both research stations and practical farms to develop a laying hen performance test under organic conditions.

In this report, results from the two research stations which tested each under semi-organic conditions in floor housing without free-range and in Station 2 in an additional small group housing system are presented. Data on laying performance, mortality and plumage condition, feed conversion and egg quality was collected and evaluated concerning differences between the four hen hybrids ISA Warren (ISA W), Lohmann Brown (LB), Lohmann Tradition (LT) and Tetra SL (TB) and between test facilities.

Laying performance was mainly affected by genotype, differences between test facilities were not significant. LB and LT performed mostly similar whereas ISA were not able to reach the level of these hybrids. TB frequently had lower performance levels than those of the other hybrids. Though visible, mortality differences were not significant. Only mortality caused by cannibalism was significantly different between test facilities. Plumage condition differed significantly between test facilities for all body parts except the neck.

Though these results show a suitability of hybrids for alternative and organic production systems, a test of hens under practical on-farm conditions, as it was part of the present project, can give further information of line performance in organic egg farming.

Keywords: Laying hen, performance test, organic egg production, feather pecking , cannibalism

ZUSAMMENFASSUNG

Trotz einer gestiegenen Nachfrage nach Eiern aus alternativen und ökologischen Haltungssystemen in Deutschland wird von Problemen mit niedrigeren Leistungen und Verhaltensstörungen wie Federpicken und Kannibalismus berichtet. Deshalb wurde ein Projekt zur Entwicklung einer Leistungsprüfung in Teststationen und in praktischen Betrieben in Leben gerufen. Hierzu wurden Daten zu Legeleistung, Mortalität, Gefiederzustand, Futterverwertung und Eiqualität der Hybriden ISA Warren (ISA W), Lohmann Brown (LB), Lohmann Tradition (LT) und Tetra SL (TB) erhoben und auf Linien- und Umweltdifferenzen geprüft.

Dieser Artikel beschreibt die Ergebnisse aus den zwei Teststationen, in denen jeweils in semi-ökologischer Haltung in Bodenhaltungsabteilen ohne Auslauf und in der einen Station zusätzlich in Kleingruppen geprüft wurde. Die Legeleistung war im Wesentlichen von der Hennen-

linie beeinflusst, Unterschiede zwischen Teststationen waren nicht signifikant. LB und LT unterschieden sich kaum in der Leistung während ISA deren Leistungsniveau nicht erreichen konnte. TB hatten oft niedrigere Leistungen als alle anderen. Obwohl sichtbar waren die Unterschiede in der Gesamt-Mortalität und in den Verlusten durch natürliche Ursachen ebenfalls nicht signifikant. Einzig die Kannibalismus-Raten unterschieden sich signifikant zwischen den Test-Einrichtungen. Im Gefiederzustand waren keine Linienunterschiede festzustellen, jedoch waren die Ergebnisse der einzelnen Stationen und Haltungssysteme in allen Körperpartien außer dem Hals signifikant verschieden. Die Unterschiede in den Verhaltensmerkmalen entstanden durch unterschiedliche Haltungsumwelten.
Obwohl die Ergebnisse dieser Untersuchungen eine Eignung der Hennen für alternative Haltungssysteme zeigen, kann ein Test unter praktischen Betriebsbedingungen weitere Information über die Leistung von Hennen in ökologischen Haltungssystemen bringen.
Stichworte: Legehenne, Leistungsprüfung, Ökologische Eiproduktion, Federpicken, Kannibalismus

CHAPTER FOUR

Field and Station Test of Laying Hens under Organic Conditions: Effects of Hybrid and Farm on Laying Performance, Mortality and Plumage Condition

Feld- und Stationsprüfung von Legehennen unter ökologischen Bedingungen: Effekte von Herkunft und Betrieb auf Legeleistung, Verluste und Gefiederzustand

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INTRODUCTION

Consumers' refusal of cage housing and approval of alternative housing systems that allow natural behavior and fulfill natural needs of animals (HÖRNING and AIGNER, 2003; BRADE, 2000) has increased in the past few decades. This demand for healthy and transparently produced food has led to a rising demand for organic production. As a result, a growing market for these products can be observed (RÖHRIG and BRAND, 2005). The organic laying hen farmer is confronted with the consumers wish to gain insight into the production system and to ensure hen welfare. This claim mainly focuses on the hens' welfare, two main parameters of accessing welfare being: hens' ability to fulfill their behavioral demands and prevention of unnatural behavior such as feather pecking and cannibalism. In contrast, the farmers' aim is to produce as many saleable eggs as possible with the lowest possible costs. His aim, as well, is a good plumage condition, as naked hens have a higher feed intake especially under cold weather conditions (LEESON and MORRISON, 1978) and may have lower production (HUBER-EICHER and SEBÖ, 2001).

Hence the hybrids purchased by the farmer must be able to compete both in high laying performance as well as in good plumage condition and low mortality. Alternative and especially organic conditions require robust hens in all traits (DAMME, 2003). As there is no independent performance test system, some farmers have difficulties finding suitable breeds for their production system.

It is known that laying performance of hen hybrids in cages (BIEDERMANN, 1997; FLOCK and HEIL, 2002) as well as broilers' (HAVENSTEIN, 2006; HUNTON, 2006) and other livestock performance (HÖRNING, 2008) was constantly improved during the 20th century. As there are many proofs for genotype-environment-interactions in laying hens (recently reviewed by e.g. GLAWATZ et al., 2007) a performance test is still needed to find the most appropriate genotypes for other housing systems than laying cages (DAMME, 1999; HARTMANN, 2000; ZEELEN 1995; ZIGGERS 1999). The inclusion of farms as test facilities may both temper the current shortage of test-capacities and deliver information about genotype-environment-interactions.

This study was initialized to plan and conduct a combined laying hen performance test on practical organic farms and in two additional test stations. Its aim was to evaluate the specifics of data from farms and to optimize future farm data analysis on laying performance. Farm and station test results for laying performance of the four hybrids ISA Warren, Lohmann Brown, Lohmann Tradition and Tetra Brown as affected by hybrid and test environment are compared. Special statistical characteristics of field data analysis are discussed separately.

Material and Methods

Experimental design

Based on power calculations 25 farms with 63 groups were initially recruited. Four commercially available hybrids frequently used in organic production were selected for inclusion in the study. These were the brown hens ISA Warren (ISA), Tetra Brown (TB), Lohmann Brown (LB) and Lohmann Tradition (LT).

During the test some farmers cancelled their participation (e.g. because of health problems, poor availability of hens or difficulties in egg sale). Finally the field test based on performance data of four hybrids in 41 groups on 16 farms, each farm kept two different genotypes. Group number per farm ranged from 2 to 4 (13x2 and 3x4 groups). They were divided into 14 groups of ISA, 13 groups of TB, seven groups of LB and seven groups of LT. One farm was excluded from the analysis because of extraordinary low performance. Tab. 1 shows the numbers of different group sizes tested.

Table 1: Numbers of farms tested and their distribution in various hen group sizes

Group size	Number of groups	Number of farms
50-300	18(17)*	7(6)*
350-1200	15	6
1300-3000	8	3
Sum	41	16

* Numbers in brackets were used for analysis of laying performance and mortality

Housing Conditions

All hens were reared under organic conditions, nevertheless five flocks on two farms had been beak trimmed during rearing, three of them LB and two LT. Seven groups were kept in an aviary system and all other groups were housed in floor systems. All groups had access to free range (except in times of avian influenza in 2006 and 2007), but seven groups did not have a winter garden. Barns for 17 groups had possibilities for automatic ventilation; all other barns had window aeration. All barns were equipped with manure boxes or deep litter without manure aeration. 33 groups could lay their eggs in group-nests; eight had access to individual nests. Most of the farmers provided 12 to 16 hours of artificial light during the day; one used additional light only in the morning to induce the laying process.

Laying hen feed was only partially produced internally on the farm. Seven farms had 33% externally produced feed, two farms had 50%, one had 66% and the other four farms obtained all feed from external feed mills. All feedstuffs were dry meal. All farms offered additional food for activity in litter area to their hens, mainly as grain but also as grit, vegetables, slaughterhouse waste or seashells.

All hens were vaccinated against IB and Newcastle Disease, the rest of the vaccination programs differed in all possible aspects. During the laying period, most of the farmers did not revaccinate. Nine groups were revaccinated against IB and six groups were revaccinated against Newcastle Disease. Five groups were given herbs against worms and 18 groups received acarine treatments using quicklime or flame cleaning. Some of the farmers used special herbs or KANNE BROTTRUNK® for fortification of hens.

Available capacities of two test-stations were added to the experiment in order to improve statistical power as well as to gain information about interactions between hen origin and test environment. This capacity included three test facilities in German test stations, one in Kitzingen/Bavaria and two in Haus Düsse/North Rhine-Westphalia. All station test hens were uniformly reared under organic conditions in Kitzingen. Their vaccination included a full program against Salmonella, Coccidiosis, Gumboro, Infectious Bronchitis (IB), Newcastle Desease (ND) and Avian Influenza. During the laying period eleven groups of each breed were housed in small groups of 25 hens each in a floor system in Kitzingen. The test in Haus Düsse included two groups of LB and two groups of ISA in a floor housing system (220 hens/group). In addition a test in the small group enriched cage system Eurovent 625 of 10, 20, 40 and 60 hens per group with six replications each was conducted. The hybrids in this system were ISA and TB in three groups per line and group size.

Though the participating test stations were not able to provide full organic housing conditions because of a lack of free range, their systems were adapted as far as possible. This was done by housing the hens in stocking rates of six hens per m^2, by abandonment of beak trimming, and by feeding organic feed. In Kitzingen no vaccination was applied during laying period, whereas Haus Düsse conducted booster vaccinations against IB and ND every 12 weeks.

Data collection

The laying period was defined as one year, meaning 364 days of lay. Some of the farms were not able to provide performance data for the whole period as hens were slaughtered before one year of lay, or as there were occasionally some days of recorded data missing.

The traits investigated on the farms were related to laying performance, mortality and plumage condition. The farmers recorded the numbers of saleable eggs, cracked and broken eggs, floor eggs and total egg number on a daily basis. These traits were both analyzed in relation to the number of hens housed and the average number of hens. Stations involved recorded the same data as the farms and in addition feed consumption and egg quality parameters such as albumen height (in Haugh Units) and breaking resistance (in Newton) three times per laying period, but these data are presented elsewhere (GLAWATZ et al., 2009b).

Mortality data were collected daily and separated into three different causes: natural death, cannibalism and slaughter because of laying stop which was practiced on eight farms. For calculation of mortality rates the number of slaughtered animals was ignored. Plumage condition was recorded three times per laying period in the first, sixth and the 11^{th} /12^{th} month of lay. Feathering of hens was evaluated by a reduced version (RLS) of the LayWel Scoring System (Complete LayWel Scoring, CLS, TAUSON et al., 2003). RLS is described in detail in GLAWATZ et al. (2009b). In brief, plumage condition was scored separately at neck, back, wings and tail with grades between 1 (largely denuded or severely damaged plumage) and 4 (intact or almost intact feathering). All plumage scoring, except the third date in Kitzingen, was conducted by the same person.

Statistical analysis

The investigated laying performance traits were analyzed concerning hybrid line differences and differences between farm and test station environments. The basic model used for the trait "Sexual maturity" was as follows:

$$\begin{aligned} yi_{jkl} &= \mu + Test\ Environment_i + Genotype_j + Season_k \\ &+ Farm_l(Test\ Environment_i) + (Test\ Environment_i \times Genotype_j) + e_{ijkl} \end{aligned} \qquad (1)$$

with Test Environment$_i$: Classification into farms and test stations; *i*=farm, station;

Line$_j$: Hybrids in test; *j*=ISA, LT, LB, TB;

Season$_k$: Quarter of housing; *k*=1,…,4;

Farm$_i$(Test Environment$_l$)*:* Nested effect of farm or test facility l within test environment i; *l*=1,…,19 and (Test Environment$_i$ x Line$_j$): Interaction between test environment and hybrid.

For plumage condition the effect of group size was added:

$$\begin{aligned} y_{ijklm} &= \mu + Test\ Environment_i + Genotype_j + Season_k + Group\ size_m \\ &+ Farm_l(Test\ Environment_i) + (Test\ Environment_i \times Genotype_j) + e_{ijklm} \end{aligned} \qquad (2)$$

with Group size$_m$: grouped herd sizes (*m*=1, …, 5; 1:10-50 hens, 2: 51-199 hens, 3: 200-899 hens, 4: 900-3000 hens). Beak trimming could no be separated from the farm effect, as four of five trimmed groups were kept on one farm, hence it was not regarded separately in statistical analysis.

All traits of laying performance were collected as time series on a daily basis and occasionally had missing values, making it impossible to use simple group means as observations. Therefore an average laying production curve within test environment of Ali-Schaeffer-type was fitted (ALI and SCHAEFFER, 1987, KRANIS et al., 2007) and correlations between daily observations from the same hen group were modeled by second-order Legendre-polynomials in a random regression approach. The model used was

$$\begin{aligned} y_{ijklmt} &= \mu + Environment_i + Genotype_j + Season_k + Farm_l(Environment_i) \\ &+ (Environment_i \times Genotype_k) + A3(Environment_i) \times \log(t_{ijklm}) \qquad (3) \\ &+ A4(Environment_i) \times [\log(t_{ijklm})]^2 + b_2 \times Z_{ijklm,t} + b_3 \times [0.5(3Z^2_{ijklm,t} - 1)] + e_{ijklmt} \end{aligned}$$

where A_3, A_4 are fixed regression coefficients on linear and squared logarithms of the time variables within environment (average environment-specific Ali-Schaeffer-type laying curve), and b_2, b_3 are correlated random regression coefficients corresponding to second order Legendre-Polynomials for each hen group with index ijklm. The standardized time variable Z_t was obtained by the transformation

$$Z_t = \frac{2(t - t_{\min}) - (t_{\max} - t_{\min})}{(t_{\max} - t_{\min})}$$

where t_{max} is day 364 of lay and t_{min} is the first day of 50% laying performance.

Mortality was analyzed by the use of the above mentioned Model 3, without the squared Legendre and both Ali-Schaeffer polynomials since mortality rates were roughly constant over time.

Contrasts between environments were estimated separately to examine differences between curves of farms and test stations. Results are presented for hybrid and for station differences and, if existent, for genotype-environment-interactions as Least Squares Means (LSM) ± Standard Error (SE). Significant effects were further analyzed using post hoc tests with Tukey-adjustments for multiple comparisons. Table 2 displays the results of the F-Tests for the investigated traits. For all calculations the procedure PROC GLIMMIX of the SAS® software (SAS INSTITUTE INC., © 2002-2003) was used.

Table 2: Results of the F-Test for hen performance traits*

	Hybrid		Test Environment		Interaction	
Trait	F	p	F	p	F	p
Sexual Maturity	6.92	0.0003	40.51	0.0001	7.88	0.0001
Laying performance per hen housed	48.65	<0.0001	1.56	0.2114	127.06	<0.0001
Laying performance per average hen	66.82	<0.0001	0.09	0.7691	12.89	<0.0001
Egg weight	36.41	<0.0001	45.36	<0.0001	26.32	<0.0001
Mortality by natural causes	1.22	0.3020	0.20	0.6542	0.52	0.6654
Cannibalism	1.22	0.2996	15.1	0.0001	0.32	0.8132
Overall Mortality	2.36	0.0690	1.44	0.2304	0.79	0.5019
Plumage neck	0.12	0.9488	1.58	0.2101	0.19	0.9006
Plumage back	3.57	0.0148	1.13	0.2885	2.45	0.0639
Plumage wings	0.79	0.4981	3.75	0.0540	0.82	0.4858
Plumage tail	2.73	0.0444	3.79	0.0529	1.86	0.1373
Overall Plumage	1.54	0.2038	2.76	0.0982	0.98	0.4021

* Numerator degrees of freedom were 3, 1 and 3 for the effects of hybrid, test environment and interaction, respectively; denominator degrees of freedom varied between 85 and 38697 according to trait.

RESULTS

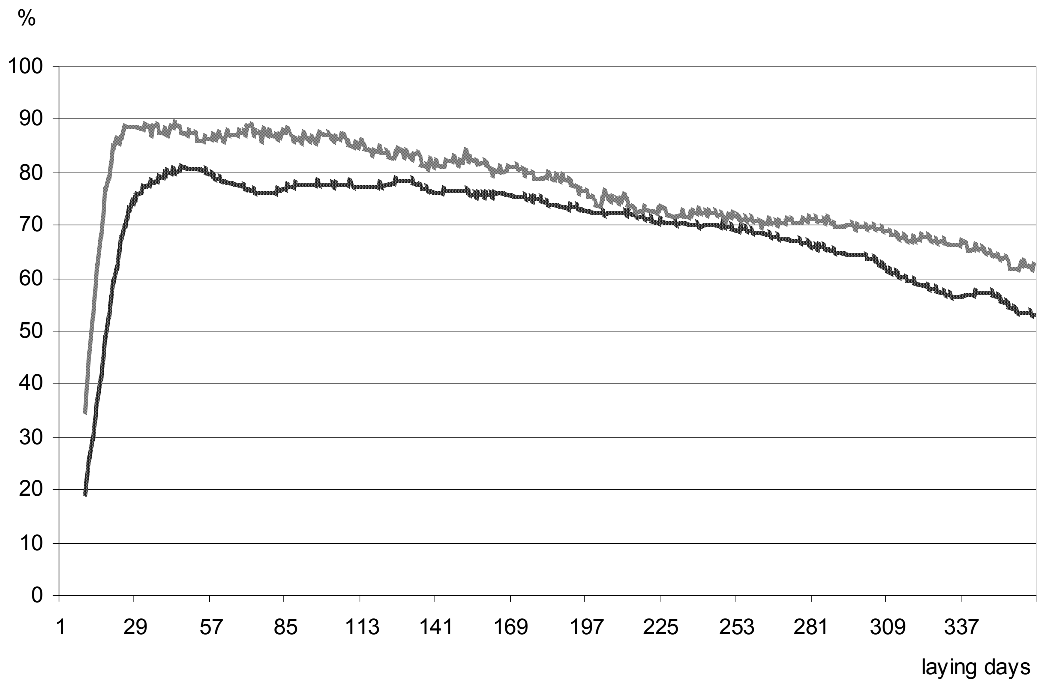
Sexual maturity as third day of over 50 % laying performance is shown for the four genotypes in Table 3. The age differed significantly between farms and test stations. The overall line effect was significant and pair-wise differences were significant for all pairs except between ISA and TB and between LB and LT. Age at third day of 50% lay was 148.7 days for TB, 157.3 for LT, 155.1 for LB and 149.9 days for ISA. It could also be shown that with regard to interaction between test environment and hen line only LB and LT in field differed significantly from all other lines in station and field and from LB and LT in station. Nevertheless the overall effect of genotype was also significant at the 0.001-level as can be seen in Table 2.

Table 3: Least Squares Means for main laying performance traits of hybrids

	Sexual maturity (d)		Laying performance per hen housed (%)		Laying performance per average hen (%)		Egg weight (g)	
Hybrid	LSM	SE	LSM	SE	LSM	SE	LSM	SE
ISA	149.9[b]	1.22	80.70[c]	0.55	85.38[a]	0.47	62.85[c]	0.16
LB	155.2[a]	1.46	83.05[a]	0.60	86.16[a]	0.53	65.62[a]	0.24
LT	157.3[a]	1.54	83.51[a]	0.58	86.08[a]	0.51	64.94[b]	0.22
TB	148.7[b]	1.33	81.81[b]	0.57	83.11[b]	0.49	63.05[c]	0.27

It could also be shown that with regard to interaction between test environment and hen line only LB and LT in field differed significantly from all other lines in station and field and from LB and LT in station. The overall effect of test environment and of interaction between test environment and genotype were significant at the 0.001-level for sexual maturity.

Figure 1: Simple means for laying performance in test stations (grey) and practical farms (black)



Overall laying performance differed between hybrids as well as between farm and station results. In Figure 1, raw means for field and for station results over all hybrids are displayed. Differences are clearly visible and the LS-means were 79.69 % in field and 84.84 % in stations. Table 4 and 5 show the results for genotypes and test environments.

Genotype-environment-interactions with shifts of rank were analyzed for all laying performance traits. Most of the differences were significant ($p<0.001$). LB hens had better performance under station conditions (e.g. 304 eggs) than under practical field conditions (e.g. 270 eggs), nevertheless both LB and LT did not differ much in their overall results, LT hens performing slightly better than LB. TB hens did not differ much in their laying performance under station and field conditions.

Table 4: Least Squares Means for main laying performance traits in farms and on station

	Sexual maturity (d)		Laying performance per hen housed (%)		Laying performance per average hen (%)		Egg weight (g)	
Environment	LSM	SE	LSM	SE	LSM	SE	LSM	SE
Farm	158.2^{a}	0.89	79.69^{b}	0.86	81.82^{b}	0.72	65.08^{a}	0.16
Station	147.3^{b}	1.53	84.84^{a}	0.67	88.55^{a}	0.58	63.14^{b}	0.23

Table 5: Least Squares Means for main laying performance traits of hybrids in farms and on station

		Sexual maturity (d)		Laying performance per hen housed (%)		Laying performance per average hen (%)		Egg weight (g)	
Evironment	Hybrid	LSM	SE	LSM	SE	LSM	SE	LSM	SE
Farm	ISA	151.5^{b}	1.55	78.37^{c}	0.87	82.12^{a}	0.74	64.34^{b}	0.18
Farm	LB	162.6^{a}	2.30	$78.47^{b.c}$	0.96	79.89^{b}	0.84	67.22^{a}	0.44
Farm	LT	168.1^{a}	2.59	79.85^{b}	0.94	83.27^{a}	0.82	65.59^{b}	0.45
Farm	TB	150.5^{b}	1.68	82.08^{a}	0.89	81.99^{a}	0.76	63.17^{c}	0.39
Station	ISA	148.3	1.63	83.04^{b}	0.67	88.64^{b}	0.59	61.36^{c}	0.23
Station	LB	147.7	1.82	87.63^{a}	0.69	92.43^{a}	0.60	64.01^{a}	0.24
Station	LT	146.4	1.99	87.16^{a}	0.70	88.88^{b}	0.61	64.28^{a}	0.25
Station	TB	146.9	1.72	81.54^{c}	0.68	84.23^{c}	0.59	62.92^{b}	0.24

Mean egg weights differed significantly between field (65.08 g) and station results (63.14 g). Hybrid differences were also clearly visible, though ISA (62.85 g) and TB (63.05 g) did not differ significantly. LB (65.62 g) and LT (64.94 g) differed slightly from each other and had higher results in comparison to other hybrids. Again, the global test for genotype-environment interactions was significant (Tab.2, $p<0.001$). In contrast to laying performance, LB had the highest egg weights of all hybrids in field (67.22 g). In station results, LB-hens reached only second rank (64.01 g).

Table 6: Least Squares Means for Mortality by natural causes, by cannibalism and overall mortality in hybrids and test environments

		Mortality by natural causes		Cannibalism		Overall Mortality	
Effect	Level	LSM	SE	LSM	SE	LSM	SE
Hybrid	ISA	11.90	1.73	5.01	0.93	17.38	1.90
	LB	9.86	2.59	4.60	1.44	13.83	2.84
	LT	9.04	2.41	4.57	1.17	13.28	2.64
	TB	8.86	2.13	3.32	1.26	12.71	2.33
Test environment	Farm	10.64	1.46	1.35^{b}	0.70	12.04	1.60
	Station	9.19	2.57	7.40^{a}	1.30	16.55	2.82

Genotype-environment-interactions were not significant for mortality rates. LS-Means are shown as hybrid differences and as differences between test environments in Table 4. Overall mortality rates were between 12.71 % (TB) and 17.38 % (ISA) for the hybrids and between 12.04 % for field farms and 16.55 % for stations. Cannibalistic losses were very low in field farms (1.35 %) and in Station 1 (0.64 %) and higher in Station 2 (8.80 % in floor housing and 11.24 % in small groups). Average rates for stations were at 7.40 %. Here the test environment had a significant effect. All other effects of hybrid and of test environment on mortality rates could not be proven statistically.

Plumage condition was on average (LS Means) between 2.8 and 4 on farms and between 2.4 and 3.78 in station facilities.

No statistical differences between field and station LS Means in any FCS were found. Furthermore, with the exception of ISA and TB hens (2.7 vs. 3.0), no difference in back feathering score was found between hybrids.

The only significant effect on plumage score was farm within test environment. It had an effect on feathering of back, wings and tail and therefore also on overall plumage condition. Table 5 shows examples of mean values for plumage condition in field and stations which demonstrate that the effect of station is due to a lower score in Station 2 which was significantly different from Station 1. All other farms did not show notable differences.

Table 7: Least Squares Means for plumage condition in blocks (farms)

		Head		Back		Wings		Tail		Overall	
Farm number	Farm/ Station	LSM	SE	LSM	SE	LSM	SE	LSM	SE	LSM	SE
F1	Farm	3.39	0.56	3.18	0.41	3.56	0.29	3.49	0.40	3.17	0.48
…	…	…	…	…	…	…	…	…	…	…	…
F16	Farm	3.75	0.43	3.07	0.36	3.81	0.26	3.77	0.35	3.83	0.37
S1	Station	3.25	0.47	3.87^a	0.33	3.92^a	0.24	3.78^a	0.32	3.51	0.40
S2	Station	2.93	0.53	2.42^b	0.41	2.71^b	0.29	2.42^b	0.40	2.42	0.45
S3	Station	3.25	0.47	2.89^b	0.33	3.32^b	0.24	2.94^b	0.32	2.90	0.40

DISCUSSION

The results of this study show that laying performance was both influenced by breeds and by test environment. The age at third day of over 50% laying performance differed notably between station and farm. The estimates for field hens may be less precise than estimates recorded at stations, because often the age of the hens on delivery is given in weeks and not in days. As described in GLAWATZ et al. (2009b), age at start of lay differed even between the 2 stations. All hens were reared at Station 1, but even then hens in Station 2 had a delayed sexual maturity. Part of these differences may be caused by stress from transport and adaptation to new housing facilities, feeding and lighting program. If this is so, most farms would have the same problem depending the way hens are delivered and differences between rearing and laying houses, as only one farm had its own rearing facility.

The impact of hybrid and of test environment was also noticeable for all main laying traits such as laying rate, egg number and egg weight. Differences in these traits due to housing systems are well known (e.g. VAN HORNE and VAN NIEKERK, 1998; BLOKHUIS et al., 2007). In the present study a difference in laying rate between farms and stations of approximately 5 to 8 % has been observed. Possible reasons may be differences in quality of feed, load with parasites and other management aspects (e.g. vaccination strategies). The difference may show how much can be gained by an improved management under practical conditions.

In addition genotype-environment interactions could be depicted (GLAWATZ et al., 2007). In contrast to station results most hen lines performed worse under practical farm conditions though TB-hens performed better in the field. This again means that results from station tests do not necessarily reflect what can be expected under practical conditions. Especially egg weight is known to be heavily affected by feeding conditions (e.g. DAMME, 1999; ANDERS-

SON et al., 2006) and therefore, the individual farm effect is quite high. This could be underlined by the effect of farm as block, which was significant. Lower egg weights under station conditions may also be explained by the use of different feed. ANDERSSON et al. showed that a higher egg weight can be achieved by a higher proportion of oil seeds as a protein carrier. Hence, the increased use of more such components in feed on practical farms may be the reason for higher egg weights observed.

Overall mortality rates were still high in both field farms as well as under station conditions. Values of 12 to 17 % for the four hybrids are high, considering that breeding companies declare mean mortality rates of about 5 % for the hybrids tested. Lambton et al. (2005) also found mortality rates of 3.47% in both conventional and organic free-range farms. In the present data differences between hybrids were visible as were differences between farms and stations even though they could not be proven significant. This is contrary to the results of AERNI et al. (2005) who found differences between hybrids but not between housing systems.

Differences in mortality caused by cannibalism were significantly higher in stations in the present study. On the other hand, mortality by natural causes was higher in farms. Overall mortality including cannibalism and natural death was 16.55 % in stations and 12 % in farms. Farmers are not able to find all dead animals under practical conditions as some are removed by predators, which may contribute to this difference. Moreover, it may be difficult for the farmers to discern cannibalistic death from natural death in some cases. This means that field data in this aspect may be regarded as less reliable than station data.

GUESDON et al. (2006) found more than 40% higher rates of cannibalism in non-beak-trimmed hens compared to trimmed. This level was not reached by any flock in the present study. High rates of cannibalism were only evident in bigger groups in one station for a longer period and in a few groups in field for shorter terms. Cannibalism reached maximum levels of 9.87 % in one farm and 11.96 and 9.21 % in Station 2 in floor and small-group housing of Station 2, respectively. All other facilities had levels between 0 and 4 %.

Various reasons for aggression and cannibalistic behavior such as high stocking densities, big group sizes and re-grouping of hens have been reported (CLOUTIER and NEWBERRY, 2002; BAUMGART, 2005), pointing to social stress as an important mediator. High rates of cannibalistic behavior in station might be explained by a low use of the sand-bath and winter garden and a resulting accumulative stocking density on wire mesh areas. ABRAHAMSSON and TAUSON (1998) reported that higher numbers of victims by cannibalism often appear suddenly. This was confirmed by the results of the present study and by the experiences of the participating farmers. Social stress and social learning as reported for cannibalism by CLOUTIER et al. (2002) could explain this. Another reason for cannibalistic behavior may be the aggravation of feather pecking leading to bloody body parts which cause cannibalism. A positive correlation between plumage damage and mortality from cannibalism was reported by KJAER and SØRENSEN (2002). Therefore severe feather pecking may also be the cause of high rates of cannibalism in some groups, though a high rate of cannibalism does not necessarily mean a high rate of feather pecking.

Feather pecking seems to be multifactorial (BAUMGART, 2005; KNIERIM et al., 2006), important factors being genetic disposition (KJAER and SØRENSEN,, 1997; KJAER et al., 2001) as well as suboptimal housing and feeding conditions. ELLIOT stated in 1996 that for a standard hybrid hen it was normal to loose up to 40 % of the plumage after 75 weeks of age, which is not acceptable from a producers' as well as from the consumers' point of view. In the present study overall feather loss did not reach such rates. Under organic field and station conditions only few hen groups had problems with naked body parts of notable size, and many groups had only little feather damages at the end of the laying period. It can be concluded that a feather loss of less than 40 % is achievable under practical conditions.

The analysis did not show notable differences between hybrids with regards to behavioral traits. Though a genetic factor for feather pecking was reported by several authors (SU et al., 2003; KJAER and HOCKING, 2004) genetic differences could not be found. The differences in plumage condition between farms and stations were not significant.

The effect of farm as block within test environment was significant for back, wings and tail as well as for overall plumage condition. A closer look at these results shows that this was caused by observable differences between feather conditions in Station 1 and 2. The high rate of feather pecking may be due to stress from change of housing conditions after rearing, to less use or availability of litter, or to different feeding regime or feeding inefficiency as discussed in GLAWATZ et al. (2009b). Light intensity is also an important factor in inducing feather pecking (KJAER and VESTERGAARD, 1999). The positive effect of smaller group sizes on plumage condition that was shown by BILÇIK and KEELING (2000), COOK et al. (2006b), HIRT (2004) and LEBRIS (2005) was visible but not significant in this study.

KJAER (2000) noted that in a comparison of brown hybrids none of them reached acceptable levels in plumage condition. This could not be confirmed by the results of the present study. All average results of hybrids were at a level of around score 3, which means that no visible part of the body has naked parts larger than 2x2 cm. Nevertheless, some groups already showed a poor feather condition at the beginning of the laying period. Better feather condition under farm conditions may also be explained by the frequent use of cockerels, which can decrease the rate of aggression within bigger laying hen flocks (BESTMAN and WAGENAAR, 2003).

Conclusions for future tests

This study was conducted as a trial for a field test system of laying hens in alternative and organic housing conditions. It can be concluded that data collected from farms is not as complete as test station data due to various practical reasons. Furthermore, farm participation is neither ensured nor indefinite. Some farms may stop participating during the investigations. To secure enough flocks (replications) per line and in order to achieve a well balanced data structure and for enough power of test a sufficient number of groups must be recruited before the start.

In addition, data can be lost during the laying period. In cases of missing data, a linear and squared regression from the Legendre-Polynomials as random first and second and a linear and squared common logarithm as third and fourth regression coefficient can be included in a model for estimating the laying curve by a regression on laying days. In addition to a good instruction of participating farmers those two measures can improve the data obtained in performance test under field conditions.

Future tests conducted on farms provide good possibilities to evaluate laying hen performance under practical conditions. As differences between farms as well as differences between farms and stations are to be due, a test on many farms and additional stations may give hints on differences in management affecting performance. Station tests are considered to be mostly optimized in their management conditions. Therefore they show optimal performance results and may be taken as “optimal facility”. On the other hand the results of this study showed that tests in different test environments may demonstrate the robustness of genotypes as e.g. TB was performing well on farms as well as on stations. And a last aspect is the collection of data on traits that cannot be taken from farms for practical or financial reasons. It can be concluded that an on-farm test of laying hens is meaningful but should still be complemented by a station test.

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SUMMARY

A study was conducted to plan and to make a test run for a combined on-farm and station evaluation of laying hen hybrids under organic conditions with regards to egg-laying, nesting behavior, egg quality, mortality, plumage condition and cannibalistism. The test included the hybrids ISA Warren (ISA), Lohmann Brown (LB), Lohmann Tradition (LT) and Tetra Brown (TB). Data on 41 hen groups were collected from 16 farms situated throughout Germany, each farm kept 2 different genotypes. Additional 44 groups were kept on Station 1 and another 28 groups on Station 2.

A statistical model including effects of test environment (farm/station), hybrid, farm (as a block effect within test environment) and interaction of test environment and hybrid was developed. For longitudinal laying performance data collected on a daily basis a laying-curve of Ali-Schaeffer-type as well as second order Legendre-Polynomials as random effects were fit to the data in order to account for occasionally missing daily observations and truncated laying periods. Mean values for laying performance per housed hen were at 79.7 % on farms and 84.8 % on stations. LB and LT hens performed better than the other hybrids under station conditions. Though not as good as LB and LT, TB had similar performances on farm as in stations. ISA showed an average laying rate and had the smallest eggs. Average feather condition score was around 3 on a scale of 0 (no feathers) to 4 (fully feathered). Cannibalism was low on-farm (1.35 %) and slightly higher on station (7.40 %).

The results showed that laying performance traits were mainly affected by hybrid and test environment (farm/station) and showed significant effects of genotype-environment-

interactions. Plumage condition and cannibalism were not affected by hybrid or test environment, but by farm within test environment. Genotype-environment-interactions were not significant for these behavioral traits.
Keywords: Laying hen, laying performance, Legendre, Longitudinal data, Feather Pecking, Cannibalism

ZUSAMMENFASSUNG

Ein Projekt zur Planung und Durchführung eines Testlaufs für eine kombinierte Leistungsprüfung von Legehennen auf ökologischen Praxisbetrieben und Stationen wurde durchgeführt, um Legeleistung, Nestverhalten , Eiqualität, Verluste, Gefiederzustand und Kannibalismus zu testen. Im Test waren die Hybriden ISA Warren (ISA), Lohmann Braun (LB), Lohmann Tradition (LT) und Tetra Braun (TB). Auf 16 Betrieben wurden Daten von 41 Hennengruppen erhoben, je Betrieb wurden zwei verschiedene Genotypen gehalten. Zusätzlich wurden 44 Gruppen auf Station 1 und weitere 28 Gruppen auf Station 2 geprüft.

Ein statistisches Modell mit den Effekten Testumwelt (Betrieb oder Station), Hybrid, Betrieb (als Blockeffekt innerhalb Testumwelt) und Interaktion zwischen Testumwelt und Hybrid wurde entwickelt. Um Fehlwerte in longitudinale Legeleistungsdaten, die täglich erhoben wurden, aus den vorhandenen Daten zu schätzen, wurden eine Legekurve des Ali-Schaeffer-Typs wie auch Legendre-Polynome zweiter Ordnung als zufällige Effekte den Daten angepasst. In der Legeleistung je Anfangshenne lagen die Mittelwerte bei 79.7 % auf den Praxisbetrieben und 84.8 in den Stationen. LB und LT hatten unter Stationsbedingungen bessere Leistungen als die anderen beiden Genotypen. TB hatte ähnliche Leistungen in den Betrieben und auf Station. ISA zeigte eine mittlere Legeleistung und hatte die kleinsten Eier. Der mittlere Gefiederzustand lag um 3 auf einer Skala zwischen 0 (keine Federn) und 4 (voll befiedert). Kannibalismus trat in den Betrieben wenig auf (1.35 %) und war höher auf Station (7.40 %).

Die Ergebnisse zeigten dass die Legeleistung hauptsächlich vom Genotyp und von der Testumwelt (Betrieb/Station) beeinflusst wurde. Der Gefiederzustand und die Kannibalismusrate wurden nicht vom Genotyp oder der Testumwelt beeinflusst, jedoch vom Betrieb innerhalb Testumwelt. Genotyp-Umwelt-Interaktionen waren für die Verhaltensmerkmale nicht signifikant.

Stichworte: Legehenne, Legeleistung, Legendre, Longitudinaldaten, Federpicken, Kannibalismus

General Discussion

Worldwide breeding of laying hen hybrids for professional egg production is in the hands of very few companies. As farmers do not get objective information on performance levels of hens from independent tests, they still have to revert to breeders' declarations which normally are not comparable between companies.

As shown in Chapter one and Table 1 of the Appendix and again by the results of this study, genotype-environment interactions complicate the comparison of results from tests under different housing conditions.

It could be calculated that a station test that is conducted in one station with less than 15 groups per line does not have a power of over 80 % for a detection of one standard deviation difference between hen lines. As one standard deviation may mean line differences in egg numbers of 20-30 eggs per hen and in mortality of 10-15 % which are quite high, the aim has to be a test under conditions which reflect practical farm conditions very well. Secondly, as demonstrated by the analyses of different experimental designs in Chapter 2 of this study, the number of test facilities must be high enough to reach a power of over 80 %. Thus the aim of future tests has to be to include as many test facilities as possible, in order to find smaller differences than one standard deviation. The effective number of farms n_e can be calculated by the use of the Matrix **K'GK**. This matrix is called correlation matrix and includes the variances of the differences between lines and their covariances. The non-diagonal elements are always half of the diagonal elements for a balanced design (App., page 9 ff). The effective number is $n_e = \frac{2}{Var_d}$ (Chapter 2). Table 5 of the Appendix displays how n_e changes with the change of experimental design (Design 12 versus Design 13). As shown on p 97 (Appendix), for balanced as well as for unbalanced designs like in the present study the effective number can be calculated as $n_e = 2 \cdot \sigma_e^2 \sqrt{\left(\frac{c}{|\mathbf{K'GK}|}\right)}$ with $c = \frac{3}{4}$ and $c = \frac{1}{2}$ or three and four genotypes, respectively.

This study showed that a block design with farms as blocks and the block size of two hen lines is an adequate approach to conduct a practicable test and reduce farm effects. A better analysis would include more hen lines per farm but this approach is not realizable as farms would not be willing to keep more than two different lines.

Field Test

The test run demonstrated that a data collection on farms may provide missing values. Tab. 7 (Appendix) lists the numbers of expected and of effectively found datasets in farms and stations. Some farms have missing days in the beginning, some in the middle and some in the end of the laying period; the latter are caused by a stop of data collection due to a mixing of hen groups or other management problems. The number of missing days was up to 156 days per hen group. Though some sets were such incomplete, data analysis could be conducted satisfactorily by the use of additional polynomial effects in the model. Those polynomials model their own laying curve by which missing values in the longitudinal datasets may be estimated. Instead of models which require complete data rows per group, the used "random regression" model provided a good possibility to weight existing values of incomplete data rows.

Nevertheless outcomes concerning laying performance of this field study must be regarded critically as some hen lines such as LB and LT are represented with only half of the number of groups that ISA and TB provided. A look on raw means shows that under field conditions LT hens performed better than LB hens. LB hens were even not able to reach the level of ISA and TB hens. This is may be due to a use of LB hens mainly in smaller groups up to 300 hens (5 groups, only two groups with higher amounts) whereas LT hens were used more frequently in bigger capacities (four groups with over 300 hens and three groups less than 300 hens). Farms with bigger groups seem to have better performances than smaller ones as they are able to optimize their management and housing conditions. Small organic farms often use old buildings which cannot be adapted well to the hens' requirements and bear a higher risk for spread of diseases and vermin. Bigger farms are able to build new barns with professional housing and feeding management which may increase laying hens' welfare and consequentially performance. The adaptation of data analysis by the use of LS-means instead of raw means cannot consider these special aspects and must therefore be regarded carefully.

In spite of some problems during the test run this study presented a manageable possibility to test laying hens' performances under practical farm conditions. It could also be displayed that because of genotype-environment interactions results from station tests do not necessarily mean the same results from practical farms. It has to be concluded that station tests do not reflect real performance levels if test facilities are not adapted very properly to the practical housing conditions the hens are tested for. Hence an on-farm test may be a good way to reflect realistic conditions. It must be considered that a balanced test structure ameliorates interpretability and informational values of field test results.

Therefore a good preparation of an on-farm test is essential to get informative results. The effect of season may be excluded by analog starts of laying period for all participating test groups. A long time of planning and an involvement of all people affected by the egg production system, such as young hen rearing farmers, laying hen farmers and their staff as well as feed mills and consultants, may assure the simultaneous supply with the requested hen lines and a preferably balanced and complete data structure.

To improve the test conditions concerning farmers' mentoring and decrease the number of cancelling farms and missing values in the data, some expert system should be established. LOKHORST and LAMAKER showed in 1996 possibilities to collect data from a daily production process control which was done by computer. A similar procedure is already conducted by some farms in Germany. It is coached by consultants and may be a source of information on hen performance as well. Other scientific works as well as the present study showed that a visiting system of experts, e.g. in charge, may be a part of supervision.

As could be shown by a separate examination being part of this study, a reduced feather condition scoring system from a distance without crating and handling of hens may reduce stress and save time (KJAER et al., 2008). The correlation of this reduced system to a full scoring system which includes crating and handling of animals was mostly over 80 %. In addition a correlation between different observers was measured with over 80%. Hence it may be possible to have a team of observers visiting farms and ease up data collection by that. A direct observation of behavior as reported by ODÉN et al. in 2002 still seems to be too time-consuming for a field test system as described in this study.

A good training and supervision of farms is one of the most important factors to get adequate results, hence a central expert supervision may be discussed. The conduction of a future coordinated test may be optimized by this expert supervision and include regional supervisors who are capable of feather condition scoring and may stay in close contact to young hen and laying hen farmers. An integrative work of breeding companies, young hen rearers, laying hen farmers, feed mills and consultants should be the aim for a good performance control and improvement of laying hen housing and production systems.

STATION TEST

For practical reasons on-farm tests cannot provide information on all traits of interest for laying hens' performance. The station test conducted during this study was a good way to analyze traits which would have been too expensive to collect on every farm, in this case feed conversion and egg quality. Nevertheless it would be interesting to investigate particularly feed intake on practical farms as feed prices are main cost factors during the laying period. Future tests may provide data on dependence of plumage condition on feed intake and conversion.

A combination of station and field data collection can give information on traits that are not or not easily available from farms, such as hatching results etc. Moreover a summed analysis of station and field data gives hints on genotype-environment-interactions and, especially by the examination of additional traits like analyses of feedstuffs, air quality or feces, on reasons for those interactions. The co-operation with farm-consultants can develop solutions for improvement of management factors causing differences in performance of genotypes in station and farm environment.

Results from station 1 showed that good management may result in good performance of all tested hen lines. Differences in performance on station and farms, as well as differences between stations, that were shown in this study, are therefore often caused by imbalances in management and feeding regimes. This includes for example differences in rearing for on-farm tested hens as well as differences in feeding for station tested hens. The latter were considered to be the inducing factor for feather pecking and cannibalism in Station 2.

Optimized conditions with similar rearing and best housing and feeding may yield optimal results and therefore benchmark possible performance levels for the farms as could be shown in Station 1. Hence a station test can be a good amendment for field data collection. Both station and field data are appropriate ways to get information on laying hen performance, each of them on their own level and, in case of station data, for their own traits. A combination of both should be the aim for future random sample test systems for laying hens under alternative and organic conditions.

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GENERAL SUMMARY

German laying hen farmers especially with non-cage and organic housing system are confronted with a lack of independent performance test systems. Breed's declarations are not comparable and data from tests in one station are not unrestrictedly comparable to other facilities.

This study was therefore a first attempt to investigate possibilities of on-farm testing of laying hens and to design and optimize a test in alternative housing systems, in this case under organic conditions. For that purpose a comprehensive literature research was conducted in a first phase. In Chapter One it could be demonstrated that genotype-environment interactions are reported by several authors for many hen lines, management systems and traits. Against the background of a missing test system in Germany, the approach of a data collection in practical farms which reflect the whole spectrum of management and housing conditions seemed therefore again to provide a possibility to adapt test conditions to farm facilities.

On the other hand the variety of farm conditions can also be a problem for data analysis. In Chapter Two special emphasis was put on experimental design. Several designs were analyzed concerning their power of test. In all designs farms were considered as blocks in which two hen lines were kept separately. The designs varied in their number of tested lines (2 to 4) and in the numbers of hen groups and participating farms. It could be shown that a test of three hen lines and a block design with two lines per farm is mostly practicable (NORDSKOG and KEMPTHORNE, 1960). Assuming a minimum power of 80% an on-farm test requires at least 22 groups per hen line. If the same test was conducted in a test station, an effective number of 16 groups per line should be tested. Calculations showed that the same number of test groups on a smaller number of farms (meaning a higher number of test groups per farm) has no substantial effect on power.

As on-farm tests may generate problems such as loss of data they should be complemented by a station test to keep up power and to get information on traits not testable on farms such as egg quality and feed conversion. Especially in laying performance data on a daily basis missing values are to be expected. In this case laying curves can be modeled and missing values may be estimated by the use of Legendre and logarithmic polynomials as effects in the model.

The theoretical approaches could be verified during a first test run. For this test 25 farms with 63 hen groups were recruited. The tested hen lines were ISA Warren (ISA), Lohmann Brown (LB), Lohmann Tradition (LT) and Tetra SL (TB). Two additional station tests with adapted organic conditions (no beak-trimming, organic feed and stocking rates, but no free range) were conducted in Kitzingen and Haus Düsse. For this 44 hen groups including 11 groups of each hen line were kept in floor pens with 25 hens per pen. Haus Düsse tested four groups of ISA and LB with 2x220 hens per line in floor housing. In addition to that 24 groups with 12 repetitions each of ISA and TB were tested in small group housing in a Eurovent 625 system (group size 10, 20, 40 or 60 hens).

A separate analysis of station data was done by the use of a simple model with the effects of hen line, station and group size within station. Egg quality was given as accumulative data for hen lines in housing systems, thus the effect of date was included and group size was disregarded. Feed conversion was analyzed by hen line, station, laying period (1 to 13) and group size within station. Group itself could be included as a random effect.

Station data showed that the hen lines had significantly different results in almost all laying trait. LB and LT had highest performance rates which were not reached by ISA and TB. Differences in laying performance between stations could not be proven. Though they were visible line and station differences could not be proven statistically. Only cannibalistic losses were significantly higher in Haus Düsse.

While laying performance was mostly affected by hen line, behavioral traits such as plumage condition and cannibalism did not differ between lines. They were mainly affected by management differences in the stations.

For the general analysis of field and station data a similar model with the effects of hen line, farm type (practical farm/station) and farm within farm type was chosen. The fixed effects of season and in case of plumage condition group size were added. By the use of above mentioned polynomial effects missing values could be estimated.

The analysis of field and station data considering effects yielded a similar picture as in stations. However plumage condition and cannibalism were not affected by line and by farm. Again only the bigger difference in performances between the two stations resulted in a statistical measureable effect of farm within farm type. For all performances genotype-environment-interactions between hen line and farm type could be approved.

The execution and analysis of this study verified the assumption that laying hens' performance should be tested in environments which are adapted well to practical farm conditions. Therefore a field test is still a good solution. Difficulties implicated in field data collection may be counteracted by an optimized management, a sufficient number of hen groups and an adapted data analysis.

ZUSAMMENFASSUNG

Deutsche Legehennenhalter vor allem mit Nicht-Käfig-Systemen und speziell mit ökologischen Haltungsverfahren sind mit der Situation konfrontiert, dass es keine unabhängige Leistungsprüfung mehr gibt. Die Angaben der Zuchtunternehmen sind nicht untereinander vergleichbar und Daten aus Einzelprüfungen sind aufgrund von Genotyp-Umwelt-Interaktionen nicht uneingeschränkt auf die Praxis übertragbar.

Das Ziel dieser Arbeit war es daher, die Möglichkeiten einer Legeleistungsprüfung auf Praxisbetrieben zu prüfen und die Versuchsbedingungen für einen solchen Test zu planen und zu optimieren. Dazu wurden in einer ersten Phase umfassende Literaturrecherchen durchgeführt. Es konnte herausgestellt werden, dass Prüfungsergebnisse von Legehennen häufig schwierig zu interpretieren sind, da zwischen vielen Hennenlinien und Haltungsverfahren Genotyp-Umwelt-Interaktionen nachgewiesen wurden.

Das Prinzip einer Prüfung unter Praxisbedingungen scheint einerseits einen Ansatz zu bieten, um die Prüfbedingungen denen in der Praxis anzugleichen. Andererseits kann die Variabilität der Betriebe ein Problem bei der Auswertung der Daten sein. Daher wurden in einem zweiten Schritt verschiedene Versuchsdesigns aufgestellt und auf ihre Testgüte $1-\beta$ untersucht. In allen Designs wurden die Betriebe als Blocks geführt, in denen zwei Herkünfte in getrennten Gruppen gehalten werden. Die Designs variierten in der Zahl der geprüften Herkünfte (2 bis 4) und in der Zahl der Hennengruppen und Betriebe. Es konnte gezeigt werden, dass ein Test von drei Hennenlinien in einem Blockdesign mit zwei Linien pro Betrieb eine gute Variante ist. Wird eine minimale Güte von 80 % angenommen, so benötigt eine Feldprüfung mindestens 22 Gruppen pro Herkunft. Derselbe Test auf Station sollte mindestens 16 Gruppen je Herkunft testen. Die Berechnungen zeigten dass dieselbe Gruppenanzahl auf einer geringeren Anzahl Höfe, also mit höheren Gruppenzahlen je Einzelbetrieb, keinen wesentlichen Unterschied in der Testgüte aufweist.

Da Praxistests Probleme wie den Wegfall von Gruppen, Betrieben oder Daten innerhalb von Datenreihen einzelner Merkmale mit sich bringen können, sollten ergänzende Stationstests durchgeführt werden. Diese können die Güte erhalten und Ergebnisse zu zusätzlichen Merkmalen wie Futterverwertung und Eiqualität bringen. Im praktischen Testlauf wiesen die Felddaten vor allem im Bereich der täglich erfassten Legeleistung einige Fehlwerte auf. Hierfür können mittels zufälliger Legendre- und Logarithmus-Polynom-Effekte im Modell die Legekurve modelliert und die fehlenden Stellen geschätzt werden.

Die theoretischen Ansätze wurden in einem praktischen Testlauf geprüft. Dazu wurden 25 ökologisch wirtschaftende Betriebe mit 63 Hennengruppen angeworben. Im Test waren die Hybriden ISA Warren (ISA), Lohmann Brown (LB), Lohmann Tradition (LB) und Tetra SL (TB). Zusätzlich wurden auf zwei Prüfstationen in Kitzingen (Bayern) und Haus Düsse (Nordrhein-Westfalen) Prüfungen unter angepassten Ökobedingungen (keine kupierten Schnäbel, Futter und Besatzdichte nach ökologischen Richtlinien, jedoch kein Auslauf) durchgeführt. Hierzu wurden 44 Gruppen mit je elf Widerholungen pro Herkunft in Kitzingen (Bodenhaltung, 25 Hennen je Gruppe) aufgestallt. Haus Düsse testete 4 Gruppen mit zwei Herkünften und je zwei Wiederholungen (ISA und LB, 220 Hennen je Gruppe) in Bodenhaltung sowie 24 Gruppen mit je 12 Widerholungen von ISA und TB im Kleingruppensystem Eurovent 625 mit den Gruppengrößen 10, 20, 40 und 60 Hennen.
Für eine getrennte Auswertung der Stationsdaten wurde ein einfaches Modell mit den Effekten Herkunft, Station und Gruppengröße innerhalb Station gewählt. Eiqualitätsdaten lagen als Sammelergebnisse für die Linien in den einzelnen Haltungsformen vor, hier wurde der Effekt Termin der Datenerhebung einbezogen und die Gruppengröße außer acht gelassen. Die Futterverwertung wurden nach Herkunft, Station, Legeperiode (1 bis 13) und Gruppengröße innerhalb Station analysiert. Als zufälliger Effekt wurde hier die Gruppe einbezogen.
In den Stationen konnte gezeigt werden dass die Hennenlinien in fast allen Legeleistungsmerkmalen signifikant verschieden waren. LB und LT hatten die höchsten Leistungen. ISA und TB konnten diese nicht erreichen. Unterschiede zwischen den Stationen konnten nicht nachgewiesen werden. Obwohl sichtbar konnten die Unterschiede zwischen Linien und zwischen Stationen nicht statistisch belegt werden. Einzig die Verluste durch Kannibalismus waren in Haus Düsse signifikant höher.
Während die Legeleistung am meisten von der Herkunft beeinflusst waren, konnten für verhaltensbedingte Merkmale wie Gefiederzustand und Kannibalismus keine Liniendifferenzen nachgewiesen werden. Diese waren hauptsächlich vom Betrieb beeinflusst.
Für die Auswertung der Felddaten wurde ein ähnliches Modell mit den Effekten Herkunft, Betriebstyp (Praxis oder Station) und Betrieb innerhalb Betriebstyp gewählt. Zusätzlich wurden die fixen Effekte Saison sowie für den Gefiederzustand und die Gruppengröße eingefügt. Mit den vorher genannten polynomialen Effekten konnten Fehlwerte überbrückt werden.
Die gemeinsame Auswertung der Daten von Praxisbetrieben und Stationen ergab bezüglich der Effekte ein ähnliches Bild wie die der Stationen. Jedoch konnten für Gefiederzustand und Kannibalismus keine Effekte der Linie und des Betriebes festgestellt werden. Erneut kam nur

der größere Unterschied in der Leistung zwischen den einzelnen Haltungsformen auf den Stationen im Effekt Betrieb innerhalb Betriebsform statistisch zum Tragen.

Für die Leistungen konnten Genotyp-Umwelt-Interaktionen zwischen Hennenlinien und Betrieben und Stationen eindeutig bestätigt werden.

Die Durchführung und Auswertung dieser Arbeit bestätigte die Annahme, dass die Leistung Legehennen nur in Umwelten getestet werden sollte, die an die praktische Nutzung gut angepasst sind. Daher bietet sich eine Feldprüfung nach wie vor an. Den Schwierigkeiten, die eine Erhebung auf Praxisbetrieben mit sich bringt, kann durch ein gutes Management der Prüfung, eine ausreichende Zahl von Teilnehmergruppen und eine angepasste Auswertung der Daten entgegengetreten werden.

APPENDIX

Table 1. Description of housing systems in which genotype-system-interactions were verified (Heil 1985)

Reference	HL	TR	Duration PT (months)	Floor housing Comp.	Hens/ Comp.	cm^2/ hen	Cage Housing Cages	Hens/ Cage	cm^2/ Hen
GOWE (1956)	7	1	12	14(+)	21	3720	35	1	1394
NORDSKOG & KEMPTHORNE (1960)					No Inf. (Field test)				
LÜKE et al. (1973)	10	1	12	2	50	2222	20	4	492
CHRISTMAS et al. (1974)	12	3	1.) 13	4	50	2675	100	2	581
			2.) 13	4	50	2675	100	2	581
			3.) 13	4	70	1914	48	2	581
HAGGER (1974)	4	5	12	1	50	2500	18	3	533
LÜKE (1975)	8	1	12	2	50	2222	20	3	372
DICKERSON (1976)	6	1	12	6	20	2230	15	3	622
							15	5	372
HEIL (1985)	22	141	12	1	50	2500	18	3	533
				2	48	2273	30	4	506

(+) Lines were mixed, three hens per line and box; HL = Hen Line, TR = Test Runs, PT = Performance Test

Table 2. Average performance in floor- and cage-housing until 1985, differences to cage-housing and the results of the statistical significance tests of the difference between housing-systems and the interactions between hybrids and housing-systems, adapted from Heil, 1985

Reference	Laying Performance per Ø-Hen (%) Flo	Diff. Fl-Ca	Inter-action	Egg weight (g) Flo	Diff. Flo-Ca	Inter-action	Feed conversion Kg feed/kg Egg mass Flo	Diff. Flo-Ca	Inter-action	Mortality (%) Flo	Diff. Flo-Ca	Inter-action
GOWE (1956)	61	9**	-	58	0 –	**	3,35			24	5 *	-
NORDSKOG and KEMPTHORNE (1960)			**			-						-
LÜKE et al. (1973)	63	-10**	**	60	-1**	**	3,35	0,63**	**	13	0 –	-
CHRISTMAS et.al. (1974)	69	1**	-	59	-1 –	-	2,58	0,07 –	-	27	-3 –	-
	69	2**	-	58	-1 –	-	2,70	0,01 –	*	11	-5 –	-
	67	1 –	**	60	-1 –	-	2,74	0,16 –	*	9	-5 –	-
HAGGER et.al. (1974)	70	-2**	*	59	-1 **	-	2,90	0,21**		10	1 –	*
LÜKE et.al. (1975)	65	-7**	-	61	0 -	-	3,22	0,32**	*	8	0 –	**
DICKERSON et.al. (1976)	72	3**	-	59	-1 –	-	2,76	0,21**	-	11	-1 –	*
HEIL (1985)	65	-18	***	62,6	-0,2	-	2,88	0,47	***	8	1,8	-
	73	-2	***	60,9	-0,2	-	2,75	0,12	***	7,5	-0,8	-

- = n.s.: $p > 0,05$; *: $p \leq 0,05$; ** : $p \leq 0,01$; ***: $p \leq 0,001$; Flo/Fl=Floor Housing, Ca=Cage housing

Table 3. Description of the housing systems in wich interactions between commercial layer hybrids and housing system were verified since 1985

Reference	Cage housing							Aviary housing				
	HL	TR	Duration PT	Type of cage	Number of cages	Anim./cage	cm^2/animal	Type of aviary	Number of Comp.	Animal / Comp.	cm^2/Anim.	cm^2/Anim. free-range
ABRAHAMSSON & TAUSON (1995a)	3	2	14	KO	144	3	640	Lövsta		231	1052	
								Marie-lund		290	1087	
				KO	144	3	640	Lövsta		175	1389	
								Marie-lund		290	1087	
ABRAHAMSSON (1995b)	3	1		GA	12	15	600					
				AK	37	5 (4)*	600 (750)*					
				KO	81	4	600					
				PL	156	3	720					
	2	1		GA	28	15	600					
				AK	36	5	600 (750)*					
				KO	81	4	600					
				PL	156	3	720					
ABRAHAMSSON et al. (1996)	3/2	1/1		GA	24/28	15	600					
				AK	54	5 (4)*	600 (750)*					
				KO	81	4	600					
				KOS	81	4	600					
				PL	156	3	720					
LANGE (1997)	4	1	12	CO	128	5	550	Natura	8	125	588	
LEYENDECKER (2003)	2	1	No Inf.	AK	188	4	688	No Inf.	2	750	1111	2
								Floor housing with intensive free-range				
									2	750	1250	LSL: 0,4 LT: 6
VITS et al. (2005)	2	2	12	AK 1	No Inf.	10/20	753					
				AK 2	(tot. 8640	40/60	753					
				AK 3	Anim./TR)	10/20	753					

Table 4a: Scientific reports on interactions between hybrids and housing-systems since 1985

Reference	**Tested housing systems**	**Hen lines**	**Traits with interactions**	**Interaction System x Hen Line trial1/ trial2**
ABRAHAMSSON (1995b)	Conventional Cage Furnished Cage Get-away-Cage Plastic Cage	Trial 1: Dekalb XL, LSL, Shaver Trial 2: ISA, LSL	Dirty eggs Cracked eggs Bodyweight 55th week	*/n.s. n.s./*** n.s./***
ABRAHAMSSON (1995a)	Lövsta-Aviary Marielund- Aviary Cage	Dekalb XL, LSL	Feed Conversion Cracked eggs 35th week: Feet abscess Toe condition Comb wounds 55th week: Body wounds 80th week/slaughter: Broken legs/feet Feet abscess	* * * * * * * *
ABRAHAMSSON et. al. (1996)	Conventional cage Furnished Cage Get-away-Cage Conventional cage with perch	Trial 1: Dekalb XL LSL, Shaver Trial 2: ISA LSL	35th week: Plumage cleanliness Feet abscess Bumble foot syndrome Claw condition 55th week: Plumage cleanliness Feet abscess Bumble foot syndrome Claw condition	 ***/*** ***/*** n.s./* n.s./*** */*** ***/*** n.s./** n.s./***
LANGE (1997)	Cage Aviary	LSL Hisex white ISA Warren LB		Shown but n.s.

Table 4b: Scientific reports on interactions between hybrids and housing-systems since 1985

Reference	Tested housing systems	Hen lines	Traits with interactions	Interaction System x Hen Line
LEYENDECKER (2003)	Cage Intensive free-range Aviary	LSL, LT	Egg number/HH	***
			Egg number/∅-Hen	***
			Egg mass/HH/d	***
			Egg mass/∅-Hen	***
			Feed intake/Hen/d	**
			Feed intake/ kg Egg mass	**
			Egg size XL	**
			L	***
			M	***
			S	**
			Cracked and broken eggs	**
			Dirty eggs	***
			Misplaced eggs	***
			Mortality	***
			Bone strength	
			Humerus	n.s.
			Tibia	**
			Egg quality	n.s.
VITS et al. (2005)	Furnished cage Aviplus, Furnished cage Eurovent 625a(big), Furnished cage Eurovent 625A(small)	LSL, LB	Dirty eggs	**
			Cracked eggs	***
			Yolk color	*
			Haugh Units	***
			Shell weight	***
			Shell density	***

Abbreviations: HH: HH, LSL: Lohmann Selected Leghorn, LT: Lohmann Tradition
n.s.: $p > 0,05$; *: $p \leq 0,05$; ** : $p \leq 0,01$; ***: $p \leq 0,001$

CHAPTER 2: CALCULATION OF THE NONCENTRALITY PARAMETER AND ESTIMATION OF EXPERIMENTAL DESIGNS AND THEIR POWER OF TEST

The noncentrality parameter was calculated with a program written in SAS IML using the following formula:

$$NC = (\mathbf{K'b} - \mathbf{m})'(\mathbf{K'GK})^{-1}(\mathbf{K'b} - \mathbf{m}) / 2\sigma \qquad \text{(SEARLE, 1971, p 190)}$$

An example for a SAS-program including five farms and three hen lines looks as follows:

```
data Xmat;
 input co1-co9;
 cards;
<Matrix X>
proc iml;
 use Xmat; read all into X;
m={0,0};
K={0 0, 0 0, 0 0, 0 0, 0 0, 0 0, 1 1, -1 0, 0 -1};
bstart={0,0,0,0,0,0,0,1,0};
DO i=0 to 2 by 0.1;
Xt=X`;
XtX= Xt*X;
Xinv=Ginv(XtX);
b=bstart*i;
print i;
Kt=K`;
Ktb=Kt*b;
ca=Ktb-m;
cat=ca`;
KGK=Kt*Xinv*K;
KGKinv=inv(KGK);
NZP=cat*KGKinv*ca;
F=FINV(0.95,2,5);
prob=1-probf(F,2,5,NZP);
print prob;
print F;
end;
quit;
```

The used Matrix **X** describes the numbers of groups on farms and of hen lines like in the formula

$$y_{ijk} = \mu + farm_i + line_j + e_{ijk} \, .$$

In this case five farms keep three lines with two or four groups per farm.

$$\mathbf{X} = \begin{bmatrix} 1 & 1 & 0 & 0 & 0 & 0 & 1 & 0 & 0 \\ 1 & 1 & 0 & 0 & 0 & 0 & 0 & 1 & 0 \\ 1 & 0 & 1 & 0 & 0 & 0 & 1 & 0 & 0 \\ 1 & 0 & 1 & 0 & 0 & 0 & 0 & 1 & 0 \\ 1 & 0 & 0 & 1 & 0 & 0 & 1 & 0 & 0 \\ 1 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 1 \\ 1 & 0 & 0 & 0 & 1 & 0 & 1 & 0 & 0 \\ 1 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 1 \\ 1 & 0 & 0 & 0 & 0 & 1 & 0 & 1 & 0 \\ 1 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 1 \\ 1 & 0 & 0 & 0 & 0 & 1 & 0 & 1 & 0 \\ 1 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 1 \end{bmatrix}$$

X is transposed to **X'**:

$$\mathbf{X'} = \begin{bmatrix} 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \\ 1 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 1 & 1 & 1 \\ 1 & 0 & 1 & 0 & 1 & 0 & 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 1 & 0 & 0 & 0 & 1 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 & 0 & 1 & 0 & 1 & 0 & 1 \end{bmatrix}$$

The multiplication of **X** with **X'** leads to

$$\mathbf{X'X} = \begin{bmatrix} 12 & 2 & 2 & 2 & 2 & 4 & 4 & 4 & 4 \\ 2 & 2 & 0 & 0 & 0 & 0 & 1 & 1 & 0 \\ 2 & 0 & 2 & 0 & 0 & 0 & 1 & 1 & 0 \\ 2 & 0 & 0 & 2 & 0 & 0 & 1 & 0 & 1 \\ 2 & 0 & 0 & 0 & 2 & 0 & 1 & 0 & 1 \\ 4 & 0 & 0 & 0 & 0 & 4 & 0 & 2 & 2 \\ 4 & 1 & 1 & 1 & 1 & 0 & 4 & 0 & 0 \\ 4 & 1 & 1 & 0 & 0 & 2 & 0 & 4 & 0 \\ 4 & 0 & 0 & 1 & 1 & 2 & 0 & 0 & 4 \end{bmatrix}$$

The generalized Inverse $(\mathbf{X'X})^-$, which is also called G, can be computed as

$$\mathbf{G} = \begin{bmatrix} 0.03923 & 0.01654 & 0.01654 & 0.01654 & 0.01654 & -0.02694 & -0.00142 & 0.02032 & 0.02032 \\ 0.01654 & 0.44171 & -0.05829 & -0.14162 & -0.14162 & -0.08365 & -0.03072 & -0.0597 & 0.10696 \\ 0.01654 & -0.05829 & 0.4417139 & -0.14162 & -0.14162 & -0.08365 & -0.03072 & -0.0597 & 0.10696 \\ 0.01654 & -0.14162 & -0.14162 & 0.44171 & -0.05829 & -0.08365 & -0.03072 & 0.10696 & -0.0597 \\ 0.01654 & -0.14162 & -0.14162 & -0.05829 & 0.44171 & -0.08365 & -0.03072 & 0.10696 & -0.0597 \\ -0.0269 & -0.08365 & -0.08365 & -0.08365 & -0.08365 & 0.30766 & 0.12146 & -0.0742 & -0.0742 \\ -0.00142 & -0.03072 & -0.03072 & -0.03072 & -0.03072 & 0.12146 & 0.21692 & -0.10917 & -0.10917 \\ 0.02032 & -0.0597 & -0.0597 & 0.10696 & 0.10696 & -0.0742 & -0.10917 & 0.23141 & -0.10192 \\ 0.02032 & 0.10696 & 0.10696 & -0.0597 & -0.0597 & -0.0742 & -0.10917 & -0.10192 & 0.23141 \end{bmatrix}$$

The hypothesismatrix K refers to block effects in its part I and the differences between the three hen lines in part II.

$$\mathbf{K'} = \left[\overbrace{\begin{matrix} 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \end{matrix}}^{\mathrm{I}} \quad \overbrace{\begin{matrix} 1 & 0 & -1 \\ 1 & -1 & 0 \end{matrix}}^{\mathrm{II}} \right]$$

The multiplication of **K’** with **G** results in a Covariance-Matrix of the line differences which is:

$$\mathbf{K'GK} = \begin{bmatrix} 0.66667 & 0.33333 \\ 0.33333 & 0.66667 \end{bmatrix} = Var\begin{bmatrix} \Delta 1 \\ \Delta 2 \end{bmatrix}$$

Hence is

$$(\mathbf{K'GK})^{-1} = \begin{bmatrix} 2 & -1 \\ -1 & 2 \end{bmatrix}$$

with

$$\mathbf{K'b} - \mathbf{m} = \begin{bmatrix} -1\sigma \\ 0 \end{bmatrix}.$$

It can be shown that the covariances in **K’GK** are always half of the variances in the diagonals if the experimental design is balanced.

It is

$$Var\begin{bmatrix}\mu_1\\ \mu_2\\ \mu_3\end{bmatrix}=\begin{bmatrix}\frac{\sigma^2}{n} & 0 & 0\\ 0 & \frac{\sigma^2}{n} & 0\\ 0 & 0 & \frac{\sigma^2}{n}\end{bmatrix}$$

and

$$\begin{bmatrix}\Delta_1\\ \Delta_2\end{bmatrix}=\begin{bmatrix}\mu_1-\mu_2\\ \mu_1-\mu_3\end{bmatrix}=\mathbf{K'b}=\begin{bmatrix}1 & -1 & 0\\ 1 & 0 & -1\end{bmatrix}\cdot\begin{bmatrix}\mu_1\\ \mu_2\\ \mu_3\end{bmatrix}$$

therefore is

$$Var(\mathbf{K'b})=\mathbf{K'}\cdot Var(\mathbf{b})\cdot\mathbf{K}$$

$$=\begin{bmatrix}1 & -1 & 0\\ 1 & 0 & -1\end{bmatrix}\cdot\begin{bmatrix}\frac{\sigma^2}{n} & 0 & 0\\ 0 & \frac{\sigma^2}{n} & 0\\ 0 & 0 & \frac{\sigma^2}{n}\end{bmatrix}\cdot\begin{bmatrix}1 & 1\\ -1 & 0\\ 0 & -1\end{bmatrix}$$

$$=\begin{bmatrix}\frac{\sigma^2}{n} & \frac{\sigma^2}{n} & 0\\ \frac{\sigma^2}{n} & 0 & \frac{\sigma^2}{n}\end{bmatrix}\cdot\begin{bmatrix}1 & 1\\ -1 & 0\\ 0 & -1\end{bmatrix}$$

$$=\begin{bmatrix}2\frac{\sigma^2}{n} & \frac{\sigma^2}{n}\\ \frac{\sigma^2}{n} & 2\frac{\sigma^2}{n}\end{bmatrix}=2\frac{\sigma^2}{n}\cdot\begin{bmatrix}1 & \frac{1}{2}\\ \frac{1}{2} & 1\end{bmatrix}$$

where the latter matrix contains correlations between treatment differences, which are $\frac{1}{2}$ in all cases as far as the design is balanced.

The comparison of a balanced design A with three lines on one farm with a balanced design B of three lines on two farms shows this again.

For design A the model is

$$y_{jk}=\mu+line_j+e_{jk}\quad (j=1,2;\ k=1,2,3)$$

with the matrix

$$(\mathbf{X'X})_{\mathrm{A}} = \begin{bmatrix} n & \frac{n}{3} & \frac{n}{3} & \frac{n}{3} \\ \frac{n}{3} & \frac{n}{3} & 0 & 0 \\ \frac{n}{3} & 0 & \frac{n}{3} & 0 \\ \frac{n}{3} & 0 & 0 & \frac{n}{3} \end{bmatrix} = \begin{bmatrix} 30 & 10 & 10 & 10 \\ 10 & 10 & 0 & 0 \\ 10 & 0 & 10 & 0 \\ 10 & 0 & 0 & 10 \end{bmatrix}$$

Computing the generalized inverse **G** as Moore-Penrose-Inverse of X'X

$$(\mathbf{X'X})^{-}_{\mathrm{A}} = \mathbf{G}_{\mathrm{A}} = \begin{bmatrix} 0{,}01875 & 0{,}00625 & 0{,}00625 & 0{,}00625 \\ 0{,}00625 & 0{,}06875 & -0{,}03125 & -0{,}03125 \\ 0{,}00625 & -0{,}03125 & 0{,}06875 & -0{,}03125 \\ 0{,}00625 & -0{,}03125 & -0{,}03125 & 0{,}06875 \end{bmatrix}$$

and the transpose of matrix **K** as

$$\mathbf{K'}_{\mathrm{A}} = \begin{bmatrix} 0 & 1 & -1 & 0 \\ 0 & 1 & 0 & -1 \end{bmatrix}$$

it is

$$\mathbf{K'GK}_{\mathrm{A}} = \begin{bmatrix} 0.2 & 0.1 \\ 0.1 & 0.2 \end{bmatrix}$$

For design B the model is

$$y_{ijk} = \mu + farm_i + line_j + e_{ijk}$$

with the matrix

$$\mathbf{X'X}_{\mathrm{B}} = \begin{bmatrix} n & \frac{n}{2} & \frac{n}{2} & \frac{n}{3} & \frac{n}{3} & \frac{n}{3} \\ \frac{n}{2} & \frac{n}{2} & 0 & \frac{n}{6} & \frac{n}{6} & \frac{n}{6} \\ \frac{n}{2} & 0 & \frac{n}{2} & \frac{n}{6} & \frac{n}{6} & \frac{n}{6} \\ \frac{n}{3} & \frac{n}{6} & \frac{n}{6} & \frac{n}{3} & 0 & 0 \\ \frac{n}{3} & \frac{n}{6} & \frac{n}{6} & 0 & \frac{n}{3} & 0 \\ \frac{n}{3} & \frac{n}{6} & \frac{n}{6} & 0 & 0 & \frac{n}{3} \end{bmatrix} = \begin{bmatrix} 30 & 15 & 15 & 10 & 10 & 10 \\ 15 & 15 & 0 & 5 & 5 & 5 \\ 15 & 0 & 15 & 5 & 5 & 5 \\ 10 & 5 & 5 & 10 & 0 & 0 \\ 10 & 5 & 5 & 0 & 10 & 0 \\ 10 & 5 & 5 & 0 & 0 & 10 \end{bmatrix}.$$

In this case the Moore-Penrose inverse is

$$\mathbf{G}_{\mathrm{B}} = \begin{bmatrix} 0.0099174 & 0.0049587 & 0.0049587 & 0.0033058 & 0.0033058 & 0.0033058 \\ 0.0049587 & 0.0358127 & -0.030854 & 0.0016529 & 0.0016529 & 0.0016529 \\ 0.0049587 & -0.030854 & 0.0358127 & 0.0016529 & 0.0016529 & 0.0016529 \\ 0.0033058 & 0.0016529 & 0.0016529 & 0.0677686 & -0.032231 & -0.032231 \\ 0.0033058 & 0.0016529 & 0.0016529 & -0.032231 & 0.0677686 & -0.032231 \\ 0.0033058 & 0.0016529 & 0.0016529 & -0.032231 & -0.032231 & 0.0677686 \end{bmatrix}$$

and again $\mathbf{K'GK}_{\mathrm{B}} = \begin{bmatrix} 0.2 & 0.1 \\ 0.1 & 0.2 \end{bmatrix}$

As in this case the number of participating farms differs only slightly between the two models, the resulting **K'GK** is the same. Nevertheless it can be shown that the non-diagonal elements are again half of the diagonal elements if the design is balanced concerning genotypes. In Table 5 the evaluated experimental designs for realistic station and field tests and their **K'GK**-Matrices are shown. Their generalized inverses were computed by the use of a generalized inverse in which the first row and first column of each fixed factor is zeroed out. As these designs have bigger differences in their number of lines and farms, an increase of variances in the diagonal can be displayed when comparing designs with similar numbers of lines but different numbers of test facilities (e.g. Designs No 6, 12 and 13).
As shown above in a balanced design the Matrix **K'GK** is

$$\mathbf{K'GK} = \begin{bmatrix} 1 & \frac{1}{2} & \cdots & \frac{1}{2} \\ \frac{1}{2} & 1 & & \frac{1}{2} \\ \vdots & & \ddots & \vdots \\ \frac{1}{2} & \frac{1}{2} & \cdots & 1 \end{bmatrix} \cdot \frac{2}{n_e} \sigma_e^2$$

Its determinant can be written as

$$\left(\frac{2\sigma_e^2}{n_e} \right)^2 \cdot \left(\frac{1}{2} \right)^{d-1} \left(d\frac{1}{2} + \frac{1}{2} \right),$$

where d means the dimension of **K'GK** (number of genotypes – 1), n_e is the effective number of observations (number of groups per genotype in a balanced and completely randomized comparison of genotypes with equal variances σ_e^2) per genotype and σ_e^2 is the variance of the residual variance. This approach takes advantage of the statements of HARVILLE (2001), who stated that the determinant of a symmetric matrix with diagonal $\lambda + 1$ and non-diagonal elements x and dimension d is

$$|\mathbf{A}| = \lambda^{d-1}(dx + \lambda)$$

Including three genotypes $(d=2)$ it is

$$|\mathbf{K'GK}| = \left[\frac{2\sigma_e^2}{n_e}\right]^2 \frac{3}{4}$$

and a design with four genotypes $(d=3)$ it is

$$\mathbf{K'GK} = \left[\frac{2\sigma_e^2}{n_e}\right]^2 \frac{1}{2}.$$

The effective number of observations per genotype is therefore

$$n_e = 2\cdot\sigma_e^2\sqrt{\left[\frac{c}{|\mathbf{K'GK}|}\right]}$$

with $c=\frac{3}{4}$ and $c=\frac{1}{2}$ or three and four genotypes, respectively.

Computation of the effctive number of groups in unbalanced designs

This approach is also suitable for non-balanced designs (e.g. designs with four genotypes such as in Table 5, designs 8 and 14-16) to get a „mean“ n_e which can be related to balanced designs with equal n_e.

Table 5: Experimental designs analysed for power of test in detection of differences between genotypes in case of one genotype differing by d standard deviations from all others

No	D[1)]	Genotypes	Farms	Groups on station	Repetit.	Groups in total	Farms with two groups	Farms with four groups	Thereof farms wtih three genotypes	Farms with six groups	Matrix **K'GK**	Effective number of groups per genotype	Correlation	Power for d=1
1	D4	3	-	15	-	15	-	-	-	-	$\begin{bmatrix} 0.4 & 0.2 \\ 0.2 & 0.4 \end{bmatrix}$	5	0.5	0.2880
2	D5	3	-	33	-	33	-	-	-	-	$\begin{bmatrix} 0.18182 & 0.09091 \\ 0.09091 & 0.18182 \end{bmatrix}$	11	0.5	0.6410
3		4	-	44	-	44	-	-	-	-	$\begin{bmatrix} 0.18182 & 0.09091 & 0.09091 \\ 0.09091 & 0.18182 & 0.09091 \\ 0.09091 & 0.09091 & 0.18182 \end{bmatrix}$	11	0.5	0.6977
4	D6	3	-	45	-	45	-	-	-	-	$\begin{bmatrix} 0.13333 & 0.06666 \\ 0.06666 & 0.13333 \end{bmatrix}$	15	0.5	0.7858
5	D7	3	-	66	-	66	-	-	-	-	$\begin{bmatrix} 0.09091 & 0.04545 \\ 0.04545 & 0.09091 \end{bmatrix}$	22	0.5	0.9278
6	D8	3	-	33	2	66	-	-	-	-	$\begin{bmatrix} 0.09091 & 0.04545 \\ 0.04545 & 0.09091 \end{bmatrix}$	22	0.5	0.9274
7	D9	3	-	33	3	99	-	-	-	-	$\begin{bmatrix} 0.06061 & 0.0303 \\ 0.0303 & 0.06061 \end{bmatrix}$	33	0.5	0.9897
8	D3	4	33	-	-	66	33	-	-	-	$\begin{bmatrix} 0.18634 & 0.09506 & 0.09959 \\ 0.09506 & 0.17805 & 0.09129 \\ 0.09959 & 0.09129 & 0.19087 \end{bmatrix}$	11		0.6988

Table 5: Continuation

No	D[1)]	Genotypes	Farms	Groups on station	Repetit.	Groups in total	Farms with two groups	Farms with four groups	Thereof farms wtih three geno-types	Farms with six groups	Matrix **K'GK**	Effective number of groups per genotype	Corre-lation	Power for d=1
9	D2	3	33	-	-	66	33	-	-	-	$\begin{bmatrix} 0.12121 & 0.06061 \\ 0.06061 & 0.12121 \end{bmatrix}$	16.5	0.5	0.8142
10	D1	2	33	-	-	66	33	-	-	-	$\begin{bmatrix} 0.0606061 \end{bmatrix}$	33	-	0.5624
11	D10	3	33	33	-	99	33	-	-	-	$\begin{bmatrix} 0.07272 & 0.03636 \\ 0.03636 & 0.07272 \end{bmatrix}$	27.5	0.5	0.9712
12	D11	3	24	-	-	66	15	9	-	-	$\begin{bmatrix} 0.12121 & 0.06061 \\ 0.06061 & 0.12121 \end{bmatrix}$	16.5	0.5	0.8233
13	D12	3	24	-	-	66	15	9	6	-	$\begin{bmatrix} 0.11111 & 0.05556 \\ 0.05556 & 0.11111 \end{bmatrix}$	18	0.5	0.8566
14		4	26	-	-	68	21	4	-	1	$\begin{bmatrix} 0.125351 & 0.084507 & 0.0760563 \\ 0.084507 & 0.2816901 & 0.2535211 \\ 0.0760563 & 0.2535211 & 0.428169 \end{bmatrix}$	8.9		0.7082
15		4	17	-	-	42	13	4	-	-	$\begin{bmatrix} 0.16 & 0.08 & 0.08 \\ 0.08 & 0.415 & 0.29 \\ 0.08 & 0.29 & 0.54 \end{bmatrix}$	5.9		0.5084
16		4	26	44+24	-	136	21	4	-	1	$\begin{bmatrix} 0.056338 & 0.028169 & 0.028169 \\ 0.028169 & 0.1116984 & 0.0552993 \\ 0.028169 & 0.0552993 & 0.1203752 \end{bmatrix}$	20.2		0.9895
17		4	17	44+24	-	110	13	4	-	-	$\begin{bmatrix} 0.051195 & 0.0290118 & 0.026484 \\ 0.0290118 & 0.0946938 & 0.0578349 \\ 0.0264841 & 0.0578349 & 0.1126139 \end{bmatrix}$	23.7		0.9769

1) D = Number of Design as given in Table 1 of Chapter 2.

Figure 2: SAS-program for power analysis

```
******************************************************************************;
*** ============ Experimental plan with given vectors b, m and K ============;
******************************************************************************;
*** ========= 3 Hen lines, 33 farms, balanced plan 2 lines per farm =========;
******************************************************************************;

data Xmat;                    *** X-Matrix ***;
 input co1-co37;
 cards;
 1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 0 0
 1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 0
 1 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 0 0
 1 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 0
 1 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 0 0
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 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 1 0 0
 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 1
 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 1 0
 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 1
 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 0 0 0 0 0 0 0 0 0 0 1 0
```

```
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 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 0 0 0 0 0 0 0 0 0 1 0
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 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 0 0 0 1 0
 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 0 0 0 0 1
 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 0 0 1 0
 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 0 0 0 1
 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 0 1 0
 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 0 0 1

proc iml;
 use Xmat; read all into X;

*** ====== Form  F(H) ~ F[s,N-r,(K`b-m)`(KGK)`(K´b-m)/sig2]      ======***;
*** =======         -> noncentrality parameter             ======     ***;
*** ======                   G = (X`X)-1                   ======     ***;

Xt=X`;
XtX= Xt*X;
print XtX;
a={0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0};
XtX[1,]=transp(a);
XtX[34,]=transp(a);
XtX[,1]=a;
XtX[,34]=a;
Xinv=Ginv(XtX);
m={0,0};
K={0 0, 0 0, 0 0, 0 0, 0 0, 0 0, 0 0, 0 0, 0 0, 0 0, 0 0, 0 0, 0 0, 0 0, 0 0,
0 0, 0 0, 0 0, 0 0, 0 0, 0 0, 0 0, 0 0, 0 0, 0 0, 0 0, 0 0, 0 0, 0 0, 0 0, 0
0, 0 0, 0 0, 0 0, 1 1, -1 0, 0 -1};
bstart={0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,
1,0};
DO i=0 to 2 by 0.1;
b=bstart*i;
print i;

Kt=K`;
Ktb=Kt*b;
ca=Ktb-m;
cat=ca`;
KGK=Kt*Xinv*K;
KGKinv=inv(KGK);
NZP=cat*KGKinv*ca;
F=FINV(0.95,2,31);
prob=1-probf(F,2,31,NZP);
print prob;
END;
quit;
```

Table 6: Distribution of hen lines and housing systems on farms and test stations

Obs.	Farm	Group within farm	Number of housed hens	Hen Line	Housing System	Free range
1	S1	1	25	LB	Floor	No
2	S1	2	25	LT	Floor	No
3	S1	3	25	TB	Floor	No
4	S1	4	25	ISA	Floor	No
5	S1	5	25	LB	Floor	No
6	S1	6	25	LT	Floor	No
7	S1	7	25	TB	Floor	No
8	S1	8	25	ISA	Floor	No
9	S1	9	25	LB	Floor	No
10	S1	10	25	LT	Floor	No
11	S1	11	25	TB	Floor	No
12	S1	12	25	ISA	Floor	No
13	S1	13	25	LB	Floor	No
14	S1	14	25	LT	Floor	No
15	S1	15	25	TB	Floor	No
16	S1	16	25	ISA	Floor	No
17	S1	17	25	LB	Floor	No
18	S1	18	25	LT	Floor	No
19	S1	19	25	TB	Floor	No
20	S1	20	25	ISA	Floor	No
21	S1	21	25	LB	Floor	No
22	S1	22	25	LT	Floor	No
23	S1	23	25	TB	Floor	No
24	S1	24	25	ISA	Floor	No
25	S1	25	25	LB	Floor	No
26	S1	26	25	LT	Floor	No
27	S1	27	25	TB	Floor	No
28	S1	28	25	ISA	Floor	No
29	S1	29	25	LB	Floor	No
30	S1	30	25	LT	Floor	No
31	S1	31	25	TB	Floor	No
32	S1	32	25	ISA	Floor	No
33	S1	33	25	LB	Floor	No
34	S1	34	25	LT	Floor	No
35	S1	35	25	TB	Floor	No
36	S1	36	25	ISA	Floor	No
37	S1	37	25	LB	Floor	No
38	S1	38	25	LT	Floor	No
39	S1	39	25	TB	Floor	No
40	S1	40	25	ISA	Floor	No
41	S1	41	25	LB	Floor	No

42	S1	42	25	LT	Floor	No
43	S1	43	25	TB	Floor	No
44	S1	44	25	ISA	Floor	No
45	F1	1	1450	ISA	Floor	Yes
46	F1	2	1360	ISA	Floor	Yes
47	F1	3	1530	LT	Floor	Yes
48	F1	4	1345	LT	Floor	Yes
49	F2	1	2250	ISA	Aviary	Yes
50	F2	2	2250	TB	Aviary	Yes
51	F3	1	1000	ISA	Floor	Yes
52	F3	2	1172	TB	Aviary	Yes
53	F3	3	1020	ISA	Floor	Yes
54	F3	4	1020	TB	Floor	Yes
55	F4	1	800	ISA	Aviary	Yes
56	F4	2	900	TB	Aviary	Yes
57	F5	1	420	ISA	Floor	Yes
58	F5	2	420	TB	Floor	Yes
59	F6	1	50	LB	Floor	Yes
60	F6	2	50	LT	Floor	Yes
61	F7	1	135	ISA	Floor	Yes
62	F7	2	240	TB	Floor	Yes
63	F8	1	1000	LB	Aviary	Yes
64	F8	2	300	TB	Floor	Yes
65	F8	3	350	TB	Floor	Yes
66	F9	1	120	LB	Floor	Yes
67	F9	2	120	LT	Floor	Yes
68	F10	1	853	ISA	Floor	Yes
69	F10	2	850	TB	Floor	Yes
70	F11	1	1495	ISA	Floor	Yes
71	F11	2	1480	LT	Floor	Yes
72	F12	1	200	LB	Floor	Yes
73	F12	2	299	LB	Floor	Yes
74	F12	3	150	TB	Floor	Yes
75	F13	1	70	ISA	Aviary	Yes
76	F13	2	100	TB	Floor	Yes
77	F14	1	1192	ISA	Floor	Yes
78	F14	2	550	ISA	Floor	Yes
79	F14	3	650	TB	Floor	Yes
80	F15	1	151	ISA	Floor	Yes
81	F15	2	151	TB	Floor	Yes
82	F16	1	208	LB	Floor	Yes
83	F16	2	208	LB	Floor	Yes
84	F16	3	200	LT	Floor	Yes
85	F16	4	200	LT	Floor	Yes
86	S2	1	220	ISA	Floor	No
87	S2	2	220	ISA	Floor	No
88	S2	3	220	LB	Floor	No
89	S2	4	220	LB	Floor	No

90	S2	121	60	TB	Eurovent 625-cage	No
91	S2	122	10	TB	Eurovent 625-cage	No
92	S2	123	10	ISA	Eurovent 625-cage	No
93	S2	124	40	TB	Eurovent 625-cage	No
94	S2	125	60	ISA	Eurovent 625-cage	No
95	S2	126	20	ISA	Eurovent 625-cage	No
96	S2	127	20	TB	Eurovent 625-cage	No
97	S2	128	40	ISA	Eurovent 625-cage	No
98	S2	129	20	TB	Eurovent 625-cage	No
99	S2	1210	20	ISA	Eurovent 625-cage	No
100	S2	1211	40	TB	Eurovent 625-cage	No
101	S2	1212	60	ISA	Eurovent 625-cage	No
102	S2	1213	10	ISA	Eurovent 625-cage	No
103	S2	1214	10	TB	Eurovent 625-cage	No
104	S2	1215	40	ISA	Eurovent 625-cage	No
105	S2	1216	60	TB	Eurovent 625-cage	No
106	S2	1217	40	ISA	Eurovent 625-cage	No
107	S2	1218	60	TB	Eurovent 625-cage	No
108	S2	1219	10	TB	Eurovent 625-cage	No
109	S2	1220	10	ISA	Eurovent 625-cage	No
110	S2	1221	40	TB	Eurovent 625-cage	No
111	S2	1222	60	ISA	Eurovent 625-cage	No
112	S2	1223	20	ISA	Eurovent 625-cage	No
113	S2	1224	20	TB	Eurovent 625-cage	No

	Farm	S1	S2	S3	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10	B11	B12	B13	B14	B15	B16
Trait	groups	44	4	24	4	2	4	2	2	2	2	3	2	2	2	3	2	3	2	4
GESAH	I.V.	16016	1456	8736	1456	728	1456	728	728	728	728	1092	728	728	728	1092	728	1092	728	1456
364d	E.V.	16015	1456	8736	1379	723	1455	719	702	720	728	1013	728	708	727	1090		1083	693	989
GESDH	I.V.	16016	1456	8736	1456	728	1456	728	728	728	728	1092	728	728	728	1092	728	1092	728	1456
364d	E.V.	16015	1456	8736	1390	725	1455	719	702	720	728	1011	728	708	727	1090		1083	698	992
VERKAH	I.V.	16016	1456	8736	1456	728	1456	728	728	728	728	1092	728	728	728	1092	728	1092	728	1456
364d	E.V.	16015	-	-	1379	725	1455	719	702	720	728	-	728	708	727	1090		-	693	983
VERKDH	I.V.	16016	1456	8736	1456	728	1456	728	728	728	728	1092	728	728	728	1092	728	1092	728	1456
364d	E.V.	16015	-	-	1379	725	1454	719	702	719	728	-	728	708	727	1090		-	693	983
EZAH	I.V.	16016	1456	8736	1456	728	1456	728	728	728	728	1092	728	728	728	1092	728	1092	728	1456
364d	E.V.	44	-	-	1379	723	1455	719	702	719	728	1011	726	708	727	1090		1079	723	992
AUSS	I.V.	44*50	1456	8736	1456	728	1456	728	728	728	728	1092	728	728	728	1092	728	1092	728	1456
364d	E.V.	44*50	-	-	1380	720	1424	719	702	721	727	-	728	703	728	1090	-	-	723	992
VERLE	I.V.	16016	1456	8736	1456	728	1456	728	728	728	728	1092	728	728	728	1092	728	1092	728	1456
364d	E.V.	15884	1455	/	-	719	-	689	156	-	-	-	-	596	725	1090	516	-	719	992
VERLNAT	I.V.	16016	1456	8736	1456	728	1456	728	728	728	728	1092	728	728	728	1092	728	1092	728	1456
	E.V.	16016	1456	8736	1407	728	1456	719	704	728	728	1017	728	728	728	1092		1086	728	992
VERLKAN	I.V.	16016	1456	8736	1456	728	1456	728	728	728	728	1092	728	728	728	1092	728	1092	728	1456
	E.V.	44	1456	8736	1407	728	1456	719	704	728	728	1017	728	728	728	1092		1086	728	992
EIGEW	I.V.	44*50	4*50	24*50	4*50	2*50	4*50	2*50	2*50	2*50	2*50	3*50	2*50	2*50	2*50	3*50	2*50	3*50	2*50	4*50
	E.V.	44*50	2*49+ 2*50	24*50	-	49+38	-	35+21	48+50	54+49	51+50	-	53+53	39+46	46+28	51+28 +51		20+17 +4	40+40	3*28+ 51
FV	I.V.	44*13	4*13	24*13	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
13 periods	E.V.	44*13	-	24*13	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
EQ	I.V.	44	4	24	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
3 dates	E.V.	44	4	24	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Table 7: Ideal and actual numbers of results for main traits
GESAH= Laying rate per housed hen, daily; GESDH= Laying rate per average hen; VERKAH= Saleable eggs per housed hen; VERKDH= Saleable eggs per average hen; EZAH= Egg number per housed hen; AUSS= Non-saleable eggs per hen; VERLE=misplaced eggs per hen; VERLNAT=Mortality by natural causes; VERLKAN= Mortality by cannibalism; EIGEW= Egg weight; FV= Feed conversion; EQ=Egg quality; I.V.= Ideal Value; A.V.=Actual Value

Table 8: Numbers of oberservation for plumage condition in each farm

Trait		S1	S2	S3	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10	B11	B12	B13	B14	B15	B16	B17
Plumage 1	I.V.	44	4	24	4	2	4	2	2	2	2	3	2	2	2	3	2	3	2	4	2
Month 1	E.V.	44	4	24	4	2	4	2	2	2	2	3	2	0	2	3	2	3	2	4	2
Plumage 2	I.V.	44	4	24	4	2	4	2	2	2	2	3	2	2	2	3	2	3	2	4	2
Month 6	E.V.	44	4	24	4	2	4	2	2	2	2	3	2	2	2	3	2	3	2	4	2
Plumage 3	I.V.	44	4	24	4	2	4	2	2	2	2	3	2	2	2	3	2	3	2	4	2
Month 12	E.V.	44	4	24	4	2	4	2	2	2	2	3	2	2	0	3	2	3	2	4	2

Figure 3: SAS-GLIMMIX-program for analysis of fixed and random effects on laying rate

```
proc glimmix data=huhn.alle;
class PS btyp line saison beob;
model GESAH=PS LINE SAISON BTYP(PS) PS*LINE A3(PS) A4(PS) /solution ;
random b2 b3 /subject=beob type=un;
contrast 'Designofcurveinenvironment' b2(PS) 1 -1 b3(PS) 1 -1;
lsmeans PS Line PS*Line /adjust=tukey;
lsmeans PS Line PS*Line /at (A3 A4)=(1 1) adjust=tukey;
output out=psgesah pred resid;
run;
```

Figure 4: Graphical illustration of Legendre and common logarithmic polynomials included in linear models for longitudinal data analysis of laying performance (from WIKIPEDIA)

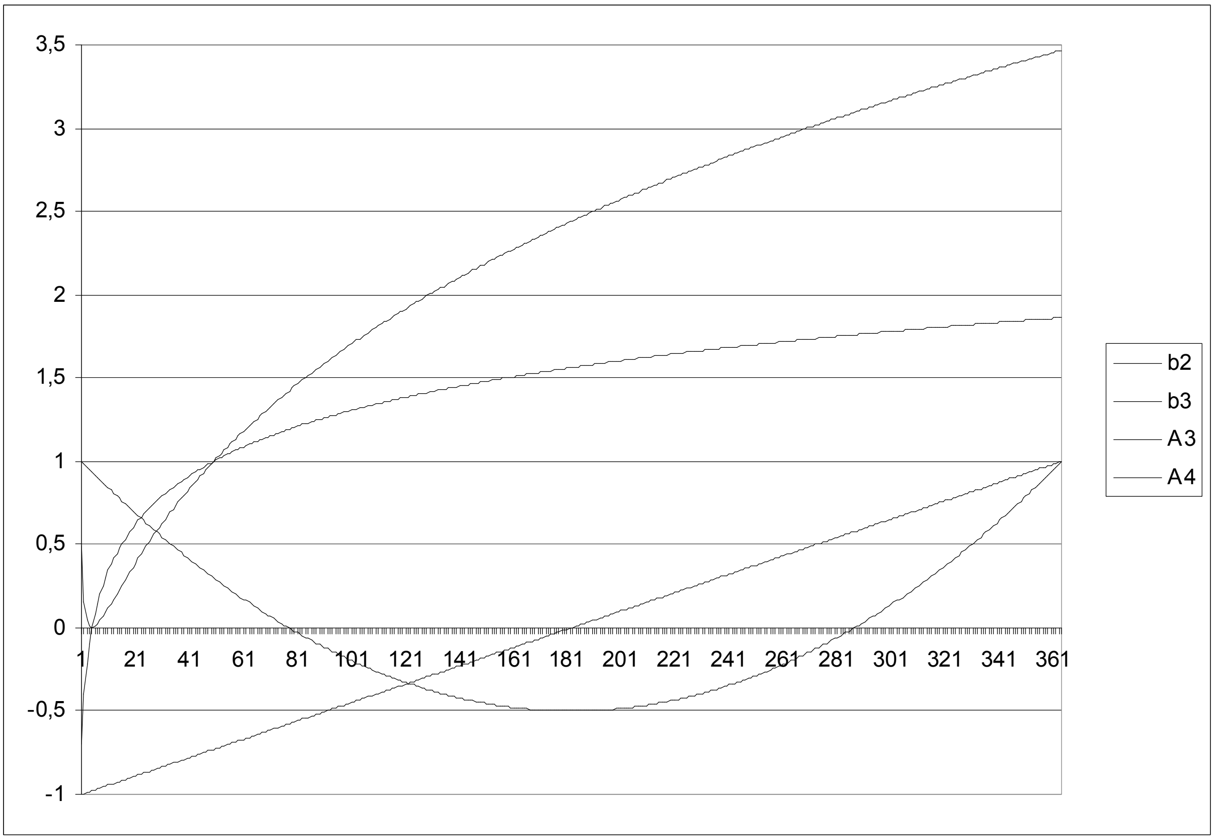

Figure 5: Comparison of polynomic curves (dark grey) and raw means of laying rates (light grey) under practical farm and station conditions

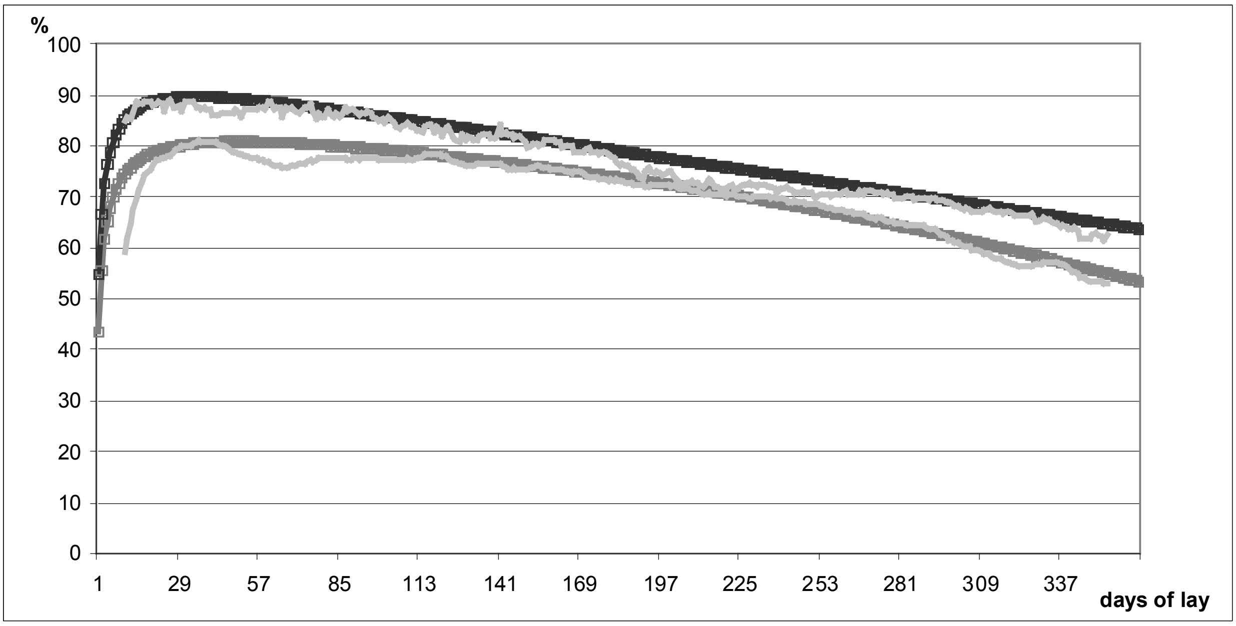

Table 8: Results of LS-Mean analysis of Plumage Condition on farms and stations (farm within farm type)

Farm number	Farm/ Station	Neck		Back		Wings		Tail	
		LSM	SE	LSM	SE	LSM	SE	LSM	SE
F1	Farm	3.39	0.56	3.18	0.41	3.56	0.29	3.49	0.40
F2	Farm	3.49	0.66	3.93	0.59	3.68	0.42	4.20	0.57
F3	Farm	3.87	0.53	3.69	0.41	3.82	0.29	3.98	0.40
F4	Farm	3.34	0.53	3.12	0.43	3.40	0.31	3.38	0.42
F5	Farm	3.06	0.50	3.10	0.38	3.24	0.27	3.09	0.37
F6	Farm	3.99	0.64	4.12	0.41	4.11	0.29	4.22	0.40
F7	Farm	3.32	0.49	3.38	0.37	3.42	0.26	3.43	0.56
F8	Farm	3.73	0.40	2.71	0.40	3.39	0.28	2.87	0.39
F9	Farm	3.52	0.64	3.51	0.37	3.78	0.27	3.57	0.36
F10	Farm	3.33	0.49	3.18	0.41	3.13	0.29	2.58	0.40
F11	Farm	3.70	0.61	2.45	0.47	3.81	0.33	3.99	0.45
F12	Farm	3.81	0.56	3.82	0.36	4.00	0.25	4.08	0.35
F13	Farm	3.79	0.46	3.85	0.38	3.59	0.27	3.66	0.36
F14	Farm	2.84	0.49	3.33	0.37	3.31	0.26	3.46	0.36
F15	Farm	3.51	0.54	3.01	0.40	3.62	0.29	3.36	0.39
F16	Farm	3.75	0.43	3.07	0.36	3.81	0.26	3.77	0.35
S1	Station	3.25	0.47	3.87^{a}	0.33	3.92^{a}	0.24	3.78^{a}	0.32
S2	Station	2.93	0.53	2.42^{b}	0.41	2.71^{b}	0.29	2.42^{b}	0.40
S3	Station	3.25	0.47	2.89^{b}	0.33	3.32^{b}	0.24	2.94^{b}	0.32

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EIDESSTATTLICHE ERKLÄRUNG

Hiermit erkläre ich, dass ich die eingereichte Dissertation mit dem Titel „Evaluating hybrid layers under organic production conditions - experimental design and test results“ selbstständig und ohne unerlaubte Hilfe verfasst, nur die von mir angegebenen Quellen und Hilfsmittel genutzt und die der benutzten Werke wörtlich oder inhaltlich entnommenen Stellen als solche kenntlich gemacht habe, sowie die Dissertation noch keiner anderen Fakultät vorgelegt habe.

Henrike Margot Hildegard Glawatz

Kiel, Februar 2009